AEROSPACE ENGINEERING

Serial Dept.
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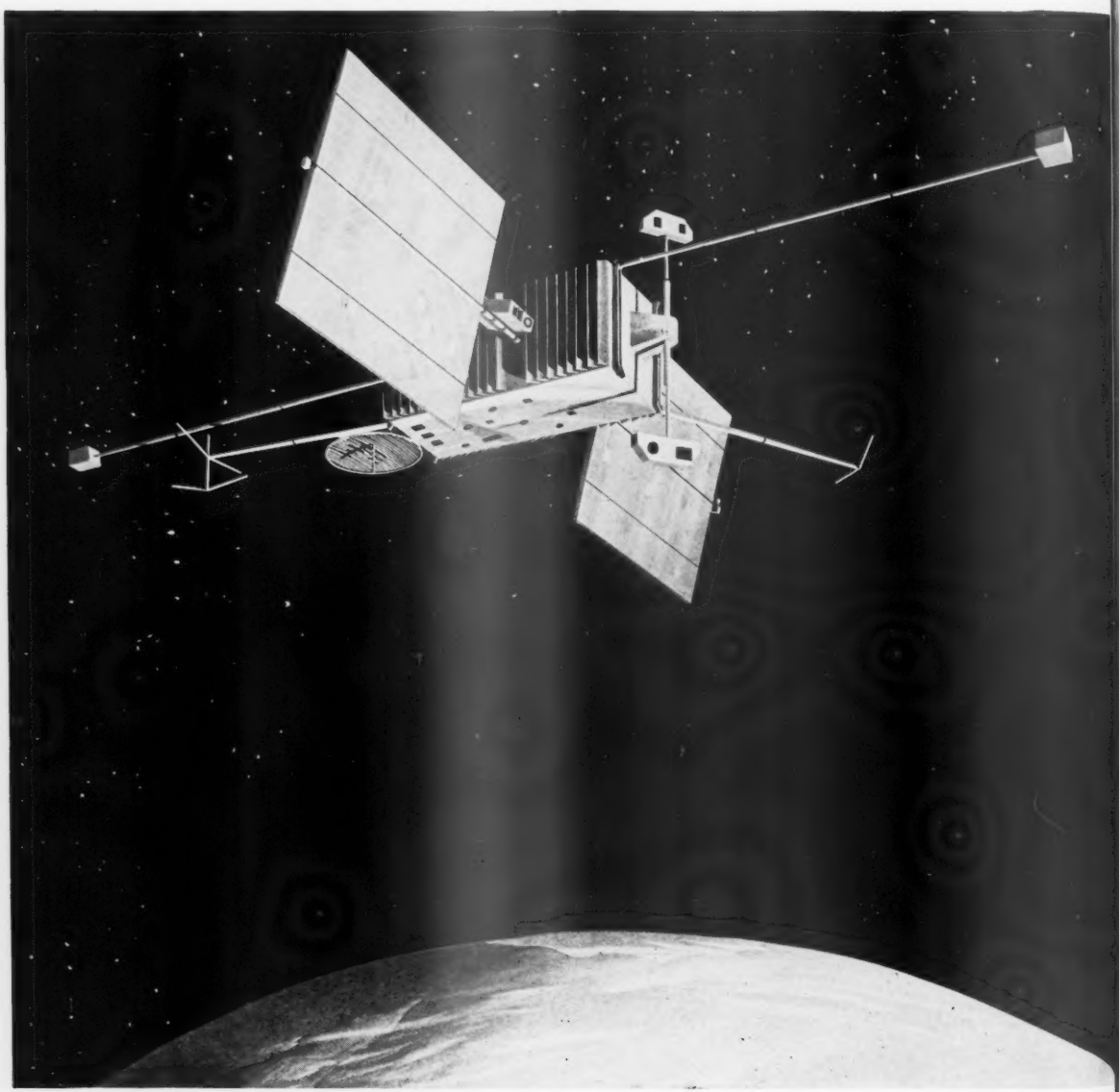

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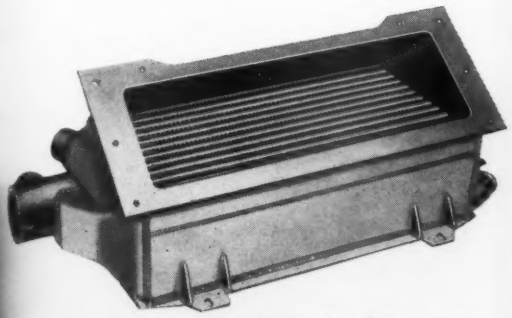

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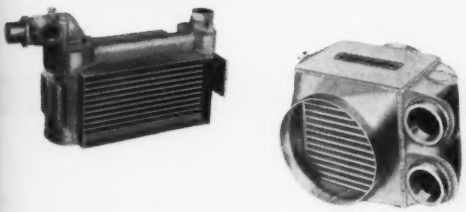

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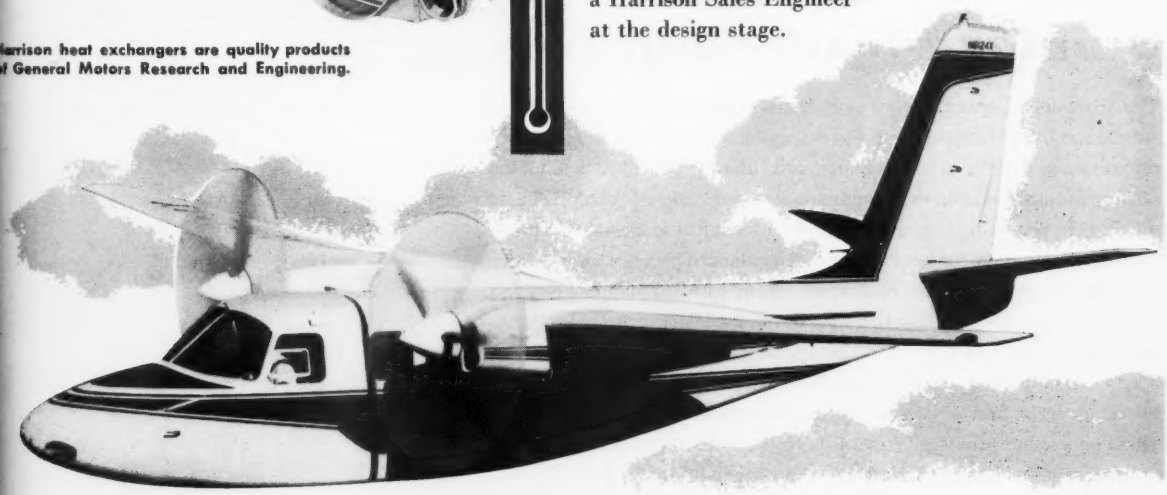

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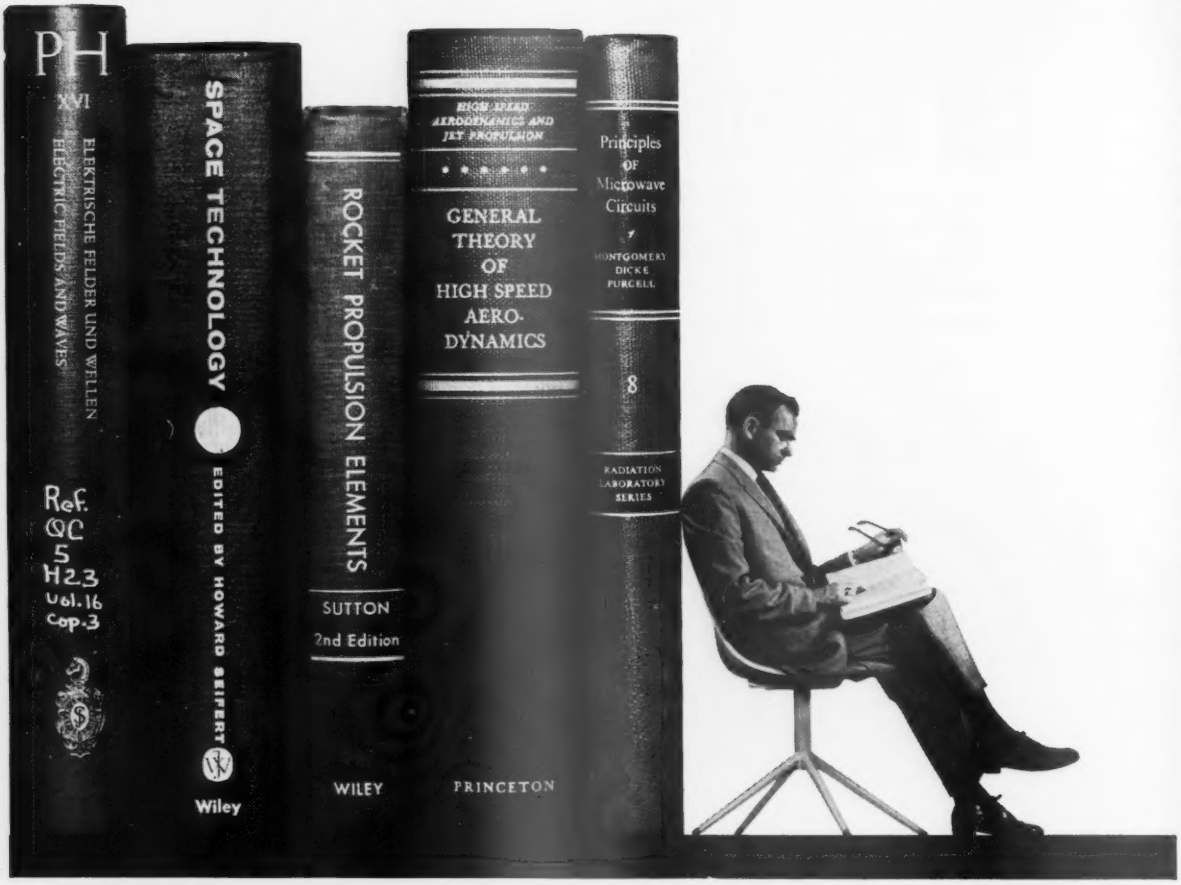

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VOLUME 20 / NUMBER 5 **MAY 1961**

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On our cover

An original oil painting by Martin Gerloff, MIAS, Aerospace Systems Design Engineer in General Electric's Missile and Space Vehicle Department, complements several articles in this issue on nuclear applications. Of it, the artist writes: "I haven't been able to find a name (maybe Nucleus?) but the work illustrates the impact on Man of nuclear power and develops modern thought from the story of Prometheus in Greek mythology. The figure—composed of bodies of varying form and color to illustrate the many countries and institutions contributing to advancement of nuclear technology—despite serious problems represented by a base of mountainous peaks, finds progress possible on Earth. The certainty of Man's engulfment and fiery destruction by unwise use of the atom is indicated by a nuclear holocaust in space shown threatening the figure."

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AEROSPACE ENGINEERING
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. . . is published monthly by the Institute of the Aerospace Sciences, Inc., at 20th and Northampton Streets, Easton, Pa. Headquarters and Editorial Offices: 2 East 64th Street, New York 21, N.Y. (TEmpleton 8-3800). Western Office: 7660 Beverly Blvd., Los Angeles 36, Calif.

Subscription rates: United States and possessions, 1 year, $5.00; single copies, $0.50. Foreign countries including Canada (American currency rates), 1 year, $6.00; single copies, $0.50.

Second-class mail privileges authorized at Easton, Pa. This publication is authorized to be mailed at the special rates of postage prescribed by Section 132.122.

Notices of change of address should be sent to the Circulation Department, Institute of the Aerospace Sciences, Inc., 2 East 64th Street, New York 21, N.Y., at least 30 days prior to actual change of address.

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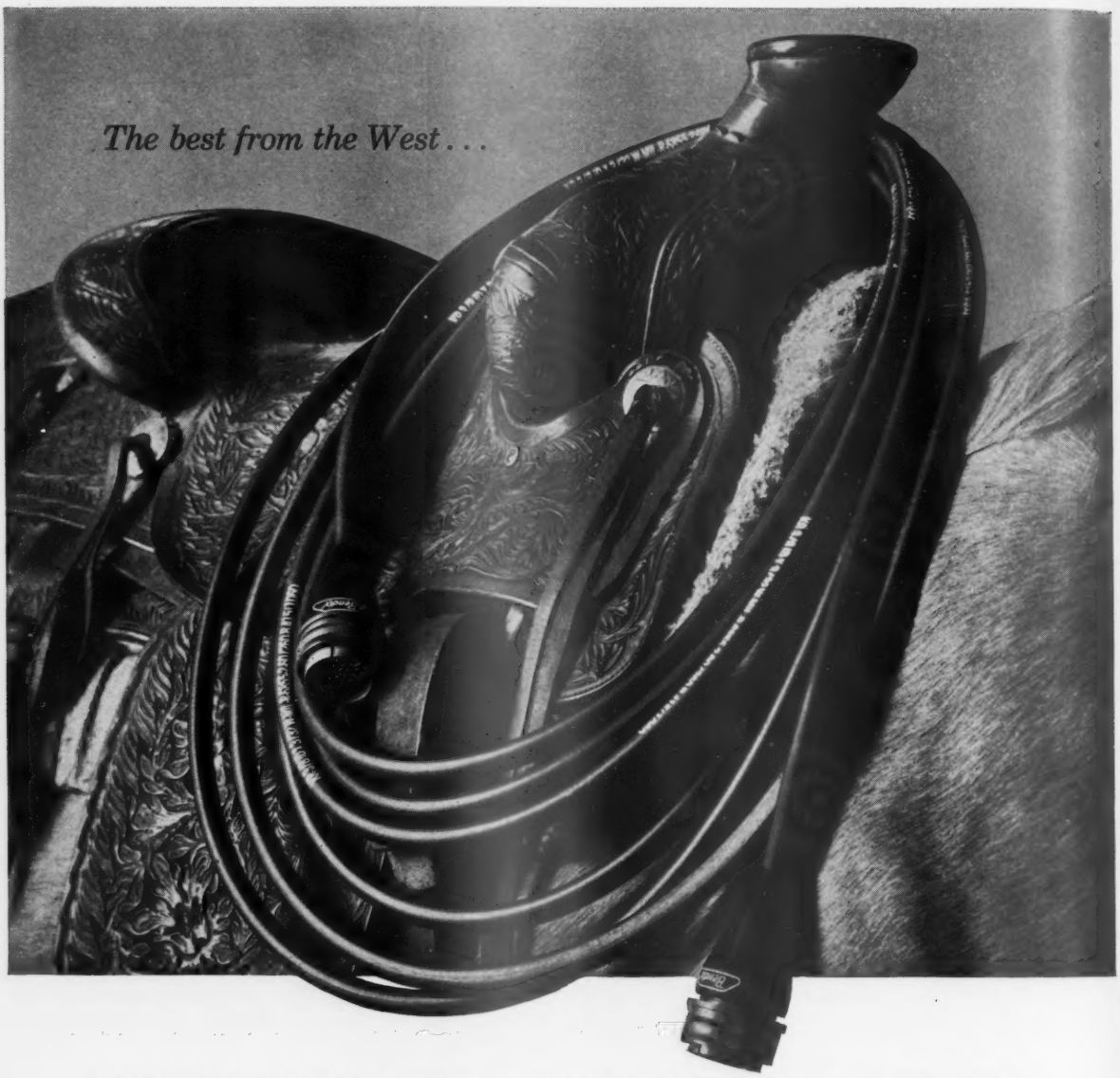

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EDITORIAL

The Pendulum Swings

THE CONFUSION which beset the U.S. Aerospace Industry in the past few years has begun to disappear as the real problems of flight in outer space have been identified and evaluated. The glamorous aspects of space exploration which tended to becloud issues at first have largely been discounted as the facts of life (political, technical and biological) have been subjected to rigorous examination. Hopes for early colonization of the Moon or for water-skiing weekends on Martian canals have been relegated to the pages of science fiction where they belong.

True, the Soviets have now put a man into space and have recovered him successfully. They have done other equally significant things in this area. Their capabilities cannot be discounted. But we should resist temptation to endeavor to match their achievements point by point at any cost just to stay in a "race." Our space programs both scientific and military must be geared to a realistic appraisal of our own needs and must not be responsive to Russian "firsts." Whether or not we are being trapped into excessive spending by our friends in the Kremlin to divert our attention and our assets in money and in brain power from other equally compelling issues is a question which may not be settled in this generation.

We know now that we have sufficiently powerful rocket motors to reach the planets and to put significant payloads into orbit in the solar system, but rocketry is only one relatively narrow band in the total spectrum of the Aerospace Sciences. In rocketry, as elsewhere, many critical problems remain to be solved before the facile dreams of the space fiction people can become reality.

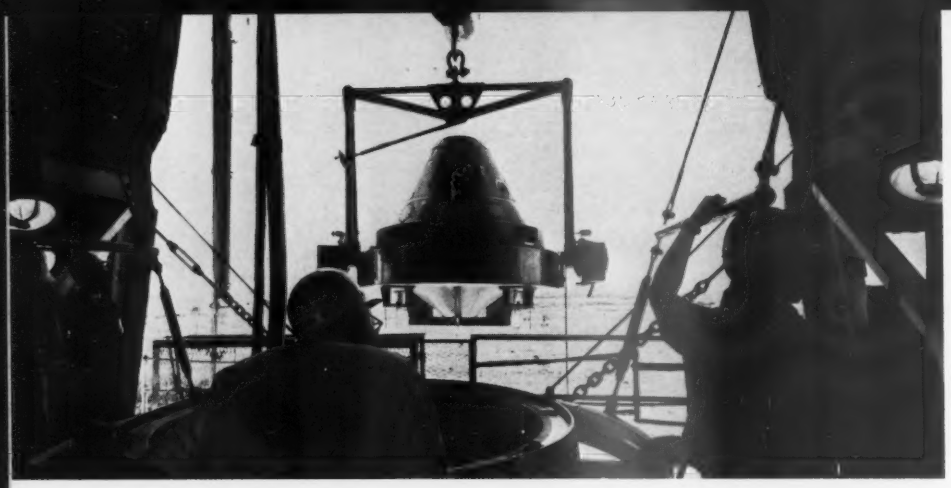
Moreover, without belittling in any way the benefits to humanity to be derived from a better understanding of the universe through space exploration, there are other (if not more important) problems nearer at hand—problems which have very real and immediate bearing on the national security and the economic welfare. It is encouraging to note that the present Administration in Washington is showing signs of sharing a similar view.

Very few of us now living, and, in fact, relatively few of our children or grandchildren, will participate personally in lunar colonization or in space exploration, but millions of us (and many times more of our descendants) will make daily use of craft flying in the earth's atmosphere for business and pleasure. Also, in spite of the lurid pictures of spaceships "shooting it out" in interstellar campaigns, this is something for the far-off future.

So, as responsible members of the IAS, it well behooves us to keep up-to-date on all aspects of the aerospace flight problem. We must continue to maintain a reasonable balance in our programs, consistent with the current professional needs of our members. It is for this reason that we have never allowed ourselves to overspecialize in any single aspect of the problem. Rocketry is important and, as a matter of record, has never been neglected by the IAS, but it is only one facet of the whole. It is for this reason that we have continued to deal also with such subjects as supersonic transports, and piloted military aircraft, and with the special tactical and logistical requirements of Army aviation.

An important Symposium in the latter area has just been held in Washington. Next month a group of IAS members will be briefed in detail on SAC problems, and, later in the summer, following the joint meeting in Los Angeles on Space Development, the Navy's air programs will be considered in the joint IAS-U.S. Navy Meeting in San Diego. These are typical examples of IAS program coverage.

In conclusion we repeat here a statement quoted from an editorial contained in the December 1957 issue of this magazine: "It has always been IAS policy in arranging its programs and in editing its publications to keep ahead of the requirements of its members . . . and so . . . we will continue to serve (in a strictly nontheological sense) the interests of our members at all altitudes from Zero to Infinity."



The Mark 2 data-capsule vehicle being swung into position atop Atlas ICBM. *Courtesy GE.*

Aerodynamics & Fluid Mechanics

Leonard C. MacAllister, MIAS, *Ballistic Research Laboratories*

Anthony M. Smith, MIAS, *General Electric Company*

IN RECENT TESTING, Air Force Atlas ICBM's have been equipped with General Electric (GE) "first generation" Mark 2 heat-sink type re-entry nose cones. During the Atlas and Thor R&D flight-test phase of this system, the Mark 2 vehicle employed an on-board data-recording package to complement the telemetry system used in gathering information concerning the flight histories of trajectories up to 5,500 nautical miles down the Atlantic Missile Range. This package, in the form of a spherical data capsule, was ejected from the nose-cone afterbody by a "jato" unit prior to water impact, and later was recovered by surface ships to yield its store of tape-recorded information.

In the original design of the capsule system, the problem of secondary body ejection through the trailing wake of a prime body was examined. This problem is of much interest today, not only with regard to data capsule systems, but also for application in the general area of recovery system deployment and "artificial" stabilizing devices of the trailing body type. Generally, two principal factors enter into consideration of secondary body ejection:

1. The deceleration of the primary body which acts to "retard" separation or deployment of the secondary system.

2. The influence of the primary body on the trailing wake flow through which the secondary body must travel. At best, this is an area of reduced dynamic pressure that prevents the ejected system from feeling the full effect of the air stream, and it may involve sizable reverse flow regions near the base of the primary body.

Basically, the secondary system must be ejected with a sufficient velocity so that it can reach a point far enough behind the main body (despite primary body deceleration and any of its wake influence) to insure continued separation or deployment under the action of air forces.

The first item is usually well defined over the en-

The author wishes to acknowledge that this work was sponsored by the Air Force Ballistic Missile Division of ARDC under Contract No. AF-04-(647)-269.

Symbols

C_D = drag coefficient, based on free stream conditions (with one exception in Eq. 3)
d = reference length, maximum diameter, ft.
L = relative distance between nose cone and capsule, $Z_1 - Z_2$, in nose cone diameters (d_1)
m = mass, lb sec²/ft.
R_N = Reynolds number, based on d_1, and free stream conditions
S = reference area, $\pi d^2/4$
V = velocity, nose cone diameters (d_1)/sec.
Z = distance along trajectory in nose cone diameters, d_1
ρ = air density, lb sec²/ft⁴
ω = frequency of fitting cosine function, rad/nose cone diameter (d_1) where d_1 = one caliber

Subscripts and Superscripts

1 = nose cone
2 = capsule
w = wake conditions
∞ = free stream conditions
R = relative quantity (cf. Eq. 3)
$\dot{}$, $\ddot{}$ = first and second derivatives, respectively, with respect to time
0 = initial conditions
$'$ = refers to drag coefficient based on wake conditions (cf. Eq. 3)

Data Capsule Ejection Through a Re-Entry Body Wake

Initial ejection velocities must be sufficiently large to ensure escape of the capsule from the nose cone.. Specifically, the ICBM Mark 2 nose cone and associated R&D data capsule have been studied to ascertain quantitatively the integrated wake/capsule interaction phenomena that occur during separation of the two bodies.

tire trajectory and can be readily inserted into the equations which describe the separation of the two bodies. The wake interaction phenomena must likewise be included and the lack of analytical and experimental information in this category was a governing factor in the present investigation.

Problem Approach

The dynamic situation encountered with the two-body separation problem greatly influenced the selection of the model free-flight technique for this investigation. A small-scale free flight system of the Mark 2 vehicle and associated capsule system were thus devised for use in the Transonic Free Flight Range[1] at the Ballistic Research Laboratories.

The most desirable approach to a ballistic range model investigation of this type is dynamic simulation. This entails the generation of an experiment that completely duplicates, on a smaller scale, the performance of the full-scale device so that it is only necessary to observe "success" or "failure" in the model system in order to predict "success" or "failure" in the full-scale case.

However, in order to gain an insight into the problems encountered in such an approach, one has only to note that, in general, area scales as the square of body diameter and mass as the cube. Thus, the scaled models tend to become light and fragile; particularly in the aft sections of a missile design that is ballasted to a forward center of mass position. This scaling feature is at odds with the strength requirements for a gun-launched model. In this case, the problem is further complicated by the necessity to scale two bodies simultaneously, and likewise maintain relative scale between the nose cone and the capsule since it is the relative difference in their performance that is desired. A detailed treatment of this scaling problem is beyond the scope of this paper, and practical design limitations negated the use of such a procedure.

It was possible to employ models of a size and strength adequate to achieve full-scale flight velocities in the region of interest, but not full-scale Reynolds numbers. Since the test R_N was an order of magnitude lower than the flight case, it imposed an

(*Continued on page 66*)

Mr. MacAllister is on the staff of the Exterior Ballistics Laboratory of the Ballistic Research Laboratories at the Aberdeen Proving Ground, Md. He received his B.A.E. degree in 1948 and his M.A.E. degree in 1949 from Rensselaer Polytechnic Institute. Upon graduation in June 1949, he joined the Ballistic Research Laboratories at Aberdeen Proving Ground. In his work at the Laboratories, he progressed through various departments and assignments to his present position as Chief of the Engineering Section of the Free Flight Aerodynamics Branch. The major portion of his assignments and endeavors have been concentrated in the field of missile dynamics.

Mr. Smith received a B.E. from The Johns Hopkins University in 1953 and an M.S.M.E. from the Drexel Institute of Technology in 1960. He has held positions in aerodynamics and fluid flow analysis with The Martin Company and Westinghouse, and has served as an Army officer on the Atlantic Missile Range. For the past 5 years, he has been associated with the General Electric Company's Missile and Space Vehicle Dept. and has been actively engaged in all phases of free flight experimentation on the Mark 2, Mark 3, RVX-1, RVX-2 and Discoverer re-entry vehicles. Currently, he is Functional Engineer of the Free Flight Experimentation Group of the Aerodynamics Operation.

"Since the computer is universal, any program can be introduced into it to establish real-time control."

Reproduction of Aircraft Dynamic Real-Time by a Digital

Henry J. Wychorski, *Sylvania Electronic Systems*

THE EVER-INCREASING computational speed of digital computers during the past few years has made possible their application in real-time computation. One new real-time application is the use of a programed digital computer to simulate the performance and flying qualities of high-performance aircraft. The computer's ability to yield an accurate response is contingent upon its ability to solve, within a short interval of time, a system of nine nonlinear differential equations with their numerous aerodynamic coefficients. In addition, an accurate response also depends upon the correct integration of the differential equations in order that the independent variables within the equation can be updated for the next cycle. To demonstrate the capabilities of the Universal Digital Operational Flight Trainer Tool (UDOFTT) in real-time computation, a specific analytic example is presented in the lead sections of this paper. Although this example is limited to only two degrees of freedom, the complete system of computation encompasses a far more complex system incorporating six degrees of freedom. The latter part of the paper presents a discussion of the results derived in the analytic example coupled with a comparison of UDOFTT with manufacturer's estimated data.

The Universal Digital Operational Flight Trainer Tool Program (UDOFTT) was designed at the Moore School of Electrical Engineering, University of Pennsylvania, and was developed by Sylvania Electronic Systems under contract N61339-40 for the U.S. Naval Training Device Center, Port Washington, N.Y., and the WADD of the Air Research and Development Command, USAF, Wright-Patterson AFB, Ohio.

The author wishes to express his thanks to L. Wendell Plum, Florence Mac Nair, John Prutsalis, and Julian Wargo of Sylvania's Data Systems Operations for assisting in the collection of data, and also for their suggestions in preparing this manuscript.

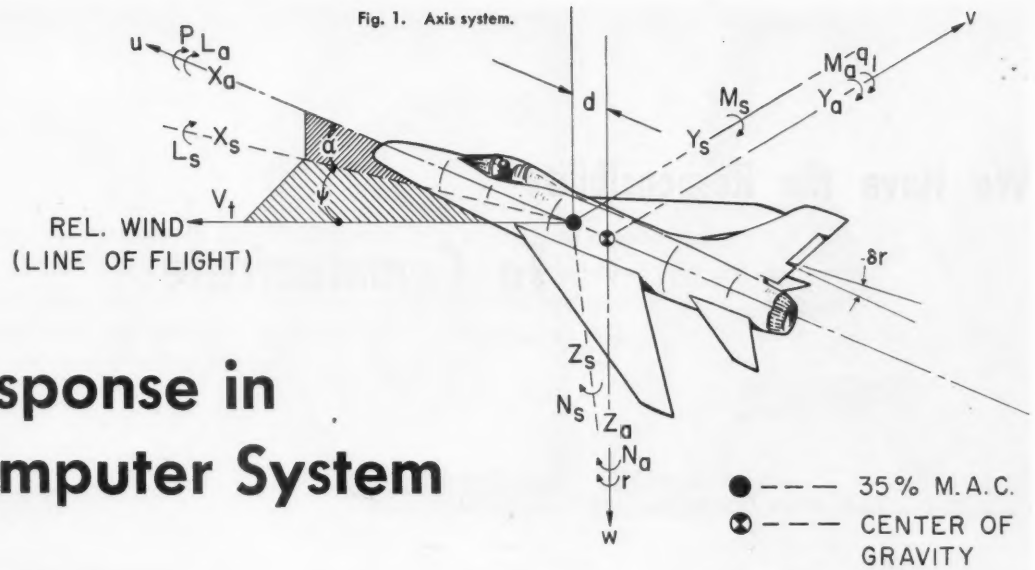
Background

In the past, a number of operational flight trainers have been constructed to describe the flight characteristics of a particular aircraft to the trainee. This was usually accomplished by analog methods where the trainee would manipulate the flight controls within a cockpit mockup of the actual aircraft. The corresponding movements would alter the flight equations within the computer where the solution yields the response of the aircraft in terms of the cockpit indicators. In UDOFTT this is accomplished through the use of a digital computer.

To establish realism, a solution has to be available in real-time. Any delays in the solution would ultimately lead to over- or undercontrol by the trainee. This response is indicative of the trainer's ability to reproduce the dynamic stability requirements of the aircraft. Similarly, the lower frequency response also is important since the aircraft is flown 90 percent of the time in a quasi-steady flight where incremental changes are small and infrequent. To accomplish this realism requires that an accurate simulation be made of the complete flight régime. This represents a monumental task for either an analog or digital computer.

The term *accurate simulation* is at best only an

Fig. 1. Axis system.



Response in Computer System

approximation of the complete system of equations required. Therefore, simulation is thought of as the degree of simulation necessary to establish realism. This degree of simulation is, in general, expressed in terms of the limitation of the computer employed. In this regard, particular aerodynamic coefficients are evaluated from the standpoint of their contribution to the overall simulation. At best, this is limited to regions where the coefficients are most significant. In addition, the system of equations where these coefficients are employed are themselves simplified,[1] thus further reducing the extent of simulation. This is done because undue complications of the equations only tend to add significantly to the computer's total parts with the result that the computer is unable to solve the existing simulation equation accurately. Accuracy, therefore, will not refer to simulation but will be treated in this paper from the standpoint of the computer's ability to reproduce the dynamic responses as indicated by the simulated equations. This subject has been explained in a report[2] on the AC analog computer systems employed in flight simulation.

The ability of UDOFTT to reproduce the flying qualities of an aircraft will therefore be a function of how accurately the extent of simulation is carried out. It is thus reasonable to expect that, if the aerodynamic data supplied by the airframe manufacturer are adhered to, the computer's output should conform to his estimated performance. For purposes of this paper, it is desirable to show how accurately the computer conforms to the simulated equations. The demonstration of accuracy will be accomplished through an analysis of the aerodynamic equations as derived by the Melpar Corporation for the F-100A Sabre-jet aircraft, and subsequently programed by Sylvania for the digital flight simulator.

For this analysis, the flying quality performance will be limited to the lateral-directional mode where the effects due to roll will not be included. It also will be assumed that the disturbance introduced into the system does not exceed the linear limits of the system. This is limited to small changes for the complete system of equations, however, because of the restrictions imposed by this analysis, it will be assumed that the larger deflection will yield com-

(*Continued on page 70*)

Mr. Wychorski received his B.E.E. degree from the Catholic University of America in 1951, and on graduation became affiliated with Nuclear Products ERCO Div. of ACF Industries responsible for the checkout of the F-86D and F9F series simulator computers. He developed equations for engine and aerodynamic mechanization for the RB66B prototype operation flight trainer and was subsequently Aero Lead Engineer responsible for the solution of equations in the preparation of test outlines for the RB66B, B66B, F4D, and B57B simulators. He also assisted in the procedures simulation of J57, P43, and P2 turbojet engines. Later, he was engaged in the design and development of missile guidance training equipment for the Atlas program. Mr. Wychorski joined the Data Systems Operations of Sylvania in December 1959, assisting in the acceptance test program for the UDOFTT; at present he is Development Engineer in the Special Projects Dept., Computer Lab. In June 1960 he received his M.E.E. from the Catholic University. Mr. Wychorski is a member of the IRE.

We Have the Responsibility To Communicate

Daniel O. Dommasch, AFIAS, *DODCO, Inc.*

IT MAY BE THAT the conservatism, instilled by conservative training of conservative technical minds, is responsible for a seeming lack of desire on the part of many engineers to establish any really effective communications with each other and with other nontechnical groups. Not that technical people may not be vocal; some are very vocal, but the question is: Do they get their ideas across? Conservatism has been blamed for the lack of creative research ability within our technical ranks. Perhaps we may blame it for other ills as well; however, if we do, then we should recognize that in a sense what is called conservatism may be only an excuse for lack of confidence or for too restrained an imagination. Possibly too much emphasis on fine, laborious detail has restricted our imaginations both in research itself and in the publication of our thoughts. Whatever the blame for the fact that scientists and engineers do not seek emphatically to express themselves, or frequently seem unable to get their thoughts across when they earnestly desire to do so, the fact remains that failure to communicate is as certainly a mistake as dropping a decimal point.

Philosophically speaking, there are no conservative processes in nature; these exist only in our imaginations. There are, moreover, no absolute physical facts; all, every single one of our theories, is an approximation. There are no absolute physical constants within the framework of our earth-bound science. Solid, substantial, certain fact is nothing but a concept which, like a baby's teething ring, provides a sense of security to the uninformed. The gaps in our knowledge are vast, so vast that we cannot comprehend them, much less start to define them. If this is so, and no modern physicist will, I think, say that things are otherwise, how can we delude ourselves into thinking that we can ever really be scientifically conservative, or that we can ever have the final answers to a general problem. Why indeed, should we be reticent to express those thoughts which have not already become ancient to the point of decay. Perhaps we fear criticism, but if we do then we don't have the courage of our convictions. We ought to realize that there are infinitely more critics than creators simply because it is infinitely easier to be critical than creative.

Engineers or scientists need fear no criticism if they are sincere, neither should they seek the refuge of silence to avoid the very fundamental responsibility of using their specialized knowledge as it needs to be used by the Nation as a whole. Never before in our national history has our survival been so utterly dependent on our technical ability.

What has this to do with the need for communication. Simply this: firm, decisive and correct guidance cannot be provided without truly effective communication. Even a casual look at our national record of comparative achievement in basic research, Government sponsored research programs and development of other than extrapolated systems cannot help but reveal that those who knew what they were about frequently failed to be convincing enough to obtain critically needed decisions. Communication is, and has been, inadequate not only among technical and nontechnical people, but also between technical specialists. The accusation has been leveled that many technical articles are incomprehensible, and even if decipherable are so cluttered with minutiae that the reader is unable to extract the point of the paper. Our communications with nontechnical people would seem to suffer from similar faults.

Civilization, as we know it, exists because of man's ability to communicate complex thoughts. It can survive only if the channels of communication are kept open by clear, concise and complete transmissions of acquired and in-progress knowledge from one group of contemporaries to another, as well as from one generation to the next.

It is my contention that we need to communicate our thoughts to others in time to do some good; we need to learn to present our case courageously and honestly; we must learn that ideas need to be sold, not just set out for inspection; we must break down the barriers which separate the various technical specialists so that the broad picture rather than just an assembly of details will be available for sale; and we need to learn to understand, to appreciate and to communicate with the very many capable people who happen not to be scientists. I think, too, that they had better learn more about the nature of our so-called scientific groups; "so-called" because I fear today the word scientist is not too meaningful in and of itself, nor has it ever been.

At a very famous university (which shall remain nameless) technical students are sometimes referred to as "educated plumbers," and, I regret, that while this statement is by no means fair, there still exists a certain amount of pertinence within it. You see, to some the word communications signifies only the mechanisms used to transmit data rather than the more fundamental thought that to communicate you need to impart knowledge; the emphasis is on the word *impart*.

An idiot can be very vocal but he imparts very little knowledge. Perhaps the technical man who tries to impart knowledge but doesn't should be compared to an idiot, but this is manifestly unfair, since, just as the idiot cannot impart knowledge, neither can he receive it. Clearly, our ability to communicate depends not only on ourselves but also on our audience. We must talk in those terms which the audience understands, otherwise our audience may possibly think that we, not they, are the idiot(s). If we do not display some judgment in our manner of approach we are open to the criticism that we do not comprehend very many of the humanistic factors which some people hold more important to the ultimate scheme of things than technical brilliance. Thus, if we want the faith of others, it is not wise to destroy that faith either by making them feel stupid or by forcing them to question our reasoning power; they may do the latter without any assistance from us.

The ability of man to communicate on a fairly high level is one of the very major factors which permit our civilization to exist; that we can communicate our more complex thoughts to our contemporaries and from one generation to the next is the cornerstone of all our progress. Were this ability destroyed, for even one generation, our civilization would vanish. Thus, communications play a dominant role in sociological balance, determination of intelligence and in our developmental sciences. Without it political groupings would vanish and our economy would become meaningless.

Very bluntly, your survival and earning power and mine both depend on (*Continued on page 31*)

Mr. Dommasch, president and founder of DODCO, Inc., was an Associate Professor of Aeronautical Engineering at Princeton University. Although his firm specializes in aircraft and missile dynamics research, his background includes both industrial and Government service in the aerodynamics, physics, the structures fields as well as design of both fixed- and rotary-wing vehicles. He has also worked on the more advanced types of systems. Author of numerous papers, reports and books in the aerodynamics field, he has served as Associate Editor for the *AGARD Flight Test Manual* series and is Advisory Technical Editor for the Pitman Publishing Corp.

Nuclear Rocket Stages Increase SATURN's

Willis Y. Jordan, Jr., Donald R. Saxton, and Paul G. Thomas

George C. *Marshall Space Flight Center, NASA*

EVEN WHEN the most optimistic appraisal of nuclear propulsion technology is made, it is clear that the available thrust level from the nuclear rocket will lag behind its chemical counterpart for many years if not indefinitely. The relative states-of-the-art would suggest that chemical propulsion systems could have an order-of-magnitude higher thrust level at the time early generation nuclear rockets could become a reality. The existence of this fact, notwithstanding the relatively high specific impulse advantage of nuclear rockets, portends either (1) the application of early generation nuclear engines to the upper stages of high thrust chemical boosters and for orbital launched spacecraft, or (2) the assignment of the nuclear rocket to the undesirable fate of remaining in an R&D status until the magnitude of its thrust level is sufficient to be attractive for lower stage use. Since the former approach offers a very attractive increase in space flight capability, the development of early generation nuclear rockets for this application appears to be a worthwhile initial objective. Increasingly higher thrust machines, which might evolve with the passing of time, should find logical applications by descending the vehicular totem pole from upper stage to lower stage use. Meanwhile, early generation nuclear rockets, if used in conjunction with the Saturn system, would substantially increase the direct orbital and escape payloads and, through the use

Mr. Jordan is a member of the Structures and Mechanics Division of the George C. Marshall Space Flight Center and is Chief of the Vehicle Evaluation Section, Future Projects Design Branch. He received a B.S. in mechanical engineering from Auburn University in 1951 and began his career with service in the USAF as a project engineer in the Propulsion Laboratory at WADC. From 1953 to 1956, he worked in propulsion and thermodynamics at the Lockheed Aircraft Corp. Mr. Jordan joined Dr. von Braun's team at Huntsville, Ala. in 1956 and has specialized in the field of nuclear rocket systems and their application to space vehicles. He is a member of the American Rocket Society.

Mr. Thomas is a member of the Future Projects Design Branch of the Structures and Mechanics Division of the George C. Marshall Space Flight Center. He received his B.S. degree in the field of mathematics from Troy (Ala.) State College in 1957. It was after graduation that Mr. Thomas joined his present organization then under ABMA jurisdiction. His work has involved trajectory analysis, flight mechanics, and vehicle optimization of the Saturn System.

Mr. Saxton, of Future Projects Design Branch, Structures and Mechanics Div., George C. Marshall Space Flight Center, received a B.S. (mech. engrg.) from Purdue Univ. (1956) and an M.S. (nuclear engrg.) from Iowa State Univ. (1958). The Army assigned him as a Scientific and Professional Soldier to MSFC (under ABMA in 1958) and after separation (1960) he stayed with MSFC in preliminary vehicle design, performance estimation, and evaluation of nuclear rocket propulsion systems.

Payload Capability

Through the use of orbital refueling operations, Saturn based nuclear rocket stages could provide the necessary transportation for attractive manned lunar operations.

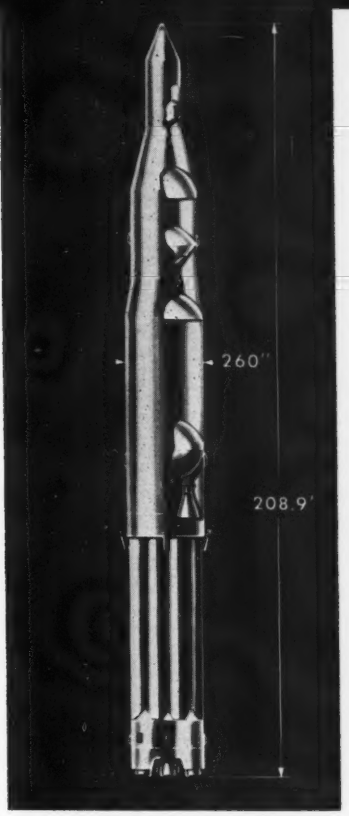


Fig. 1. Saturn C-2 (3-stage rocket).

of orbital refueling techniques, open the door to manned lunar operations and even more ambitious missions beyond.

Saturn Description

The operational version of the fully developed Saturn space vehicle will normally consist of three chemical stages which use liquid oxygen and kerosene propellants in the booster stage and liquid oxygen and liquid hydrogen in two upper stages. Each stage is propelled by a cluster of engines producing an approximate thrust level of $1^1/_2$ million lbs and 0.8 million lbs in the first and second stages, respectively, and less than 100,000 lbs in the third stage. This version of the Saturn, a sketch of which is shown in Fig. 1, is capable of lifting payloads of approximately 25 tons into low earth orbits. The following discussions indicate the growth potential which would be possible by the use of certain nuclear rocket upper stages on Saturn.

Nuclear Rocket Engines

The conventional nuclear rocket concept consists of a solid core reactor heat exchanger through which passes a working fluid that is heated to fairly typical chemical rocket chamber temperatures and expanded to a high exhaust velocity through a De Lavel nozzle. The exhaust velocity produced is a function of the propellant temperature and molecular weight $\sqrt{T/M}$, while the power production is proportional to the propellant enthalpy rise across the core. Hydrogen is chosen as the working fluid because its low molecular weight maximizes the exhaust velocity. A nomograph showing the relationship among the various parameters which influence the performance of a nuclear hydrogen rocket—i.e., temperature, I_{sp}, thrust level, power level, and nozzle expansion ratio—is shown in Fig. 2. In the subsequent discussion a theoretical propulsion system specific impulse of 800 sec is arbitrarily assumed.

Saturn-Nuclear Configurations

It is interesting to consider the following two basic applications of nuclear stages to the Saturn vehicle for direct ascent missions, (1) a nuclear third stage on top of the Saturn and (2) a relatively heavy nuclear second stage directly on top of the Saturn booster. In both, a constant nuclear stage I_{sp} of 800 sec was assumed while the thrust level in the nuclear stages was varied over a wide range to determine its influence on overall vehicular performance. The optimum propellant distribution in all stages was determined for each value of thrust level. The results are compared against the performance of a fixed standard all-chemical three-stage Saturn vehicle, as shown in Fig. 3, for both low orbital and direct escape missions.

As would be expected, (*Continued on page 38*)

Gyro Damping

E. M. Fischel, *Kearfott Division, General Precision, Inc.*

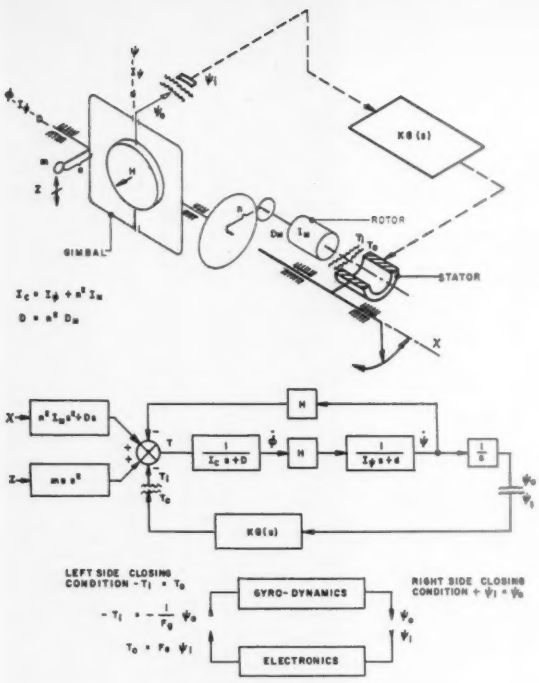


Fig. 1. Single-axis gyro platform.

THE PURPOSE of this investigation is to determine the part the damping of the gyro's precession axis plays in the design of the platform. The gyro is of the single-degree-of-freedom or rate-integrating type, whose construction features may provide for fluid floating. The damping of the precession axis can affect the platform favorably or unfavorably under different environmental conditions.

Three important cases of environmental conditions will be investigated: (A) platform at rest (on work bench), (B) platform subjected to translational oscillations (vibration table), and (C) platform subjected to rotational oscillations (wobble table). Under actual operating conditions, cases (B) and (C) occur simultaneously.

The investigation will show how the gyro and its servoloop act together under linearized conditions. For this case, recommendations can be made for the platform parameters, but for a final design, nonlinear terms in the loop—such as Coulomb friction, amplifier distortion, etc.—must be considered.

Description of the Platform

A complete platform consists of three single-degree-of-freedom rate-integrating gyros, three coordinated servoloops and, if desired, an extra gimbal—the outer roll gimbal. This latter gimbal

Dr. Fischel is currently Senior Technical Adviser at Kearfott Division, with special assignments in the development of new and advanced concepts in gyrodynamics and inertial guidance. He obtained his Ph.D. in mechanics at the University of Berlin in 1935. From 1946 to 1954 he served the U.S. Government, in an advisory capacity, at the Ordnance Research and Development Division in Texas and at the Redstone Arsenal in Alabama, in such areas as rocket guidance and measuring techniques. He has published numerous papers and holds many patents in the fields of autopilots, gyros, and guidance systems. He is also a board member of the Guidance and Navigation Committee of the ARS.

Symbols

ϕ	=	angle of gimbal referred to horizontal plane, rad
ψ	=	precession axis angle, rad
χ	=	angle of aircraft around ϕ-axis, rad
Ψ, X, Φ	=	amplitudes of ϕ, ψ, χ
z	=	coordinate of aircraft system normal to horizontal plane, cm
I_ψ	=	moment of inertia of gyro around precession axis, gr-cm-sec^2
I_ϕ	=	moment of inertia of gyro and gimbal around ϕ-axis, gr-cm-sec^2
I_M	=	moment of inertia of torque motor armature, gr-cm-sec^2
I_c	=	$I_\phi + n^2 I_M$
m	=	mass of platform, gr-sec^2/cm
e	=	mass shift, cm

Its Part in Platform Design

Gyro precession axis damping was found to have a twofold effect:
- *For loop stability, it should be large.*
- *To prevent the transmission of aircraft oscillations, it should be small.*

Investigation disclosed a simple method of determining quantitatively the optimal values of the parameters of a platform provided with single-degree-of-freedom rate-integrating gyros.

is not involved in the dynamics of the gyros and therefore is not considered here. The three gyros and their servoloops are identical in nature, differing only in the gear ratios of the motor drives and the moments of inertia of the gimbals and the gyro cluster around the various axes. If we disregard the rectification effect of the gyros, which depends on motion of the platform around two axes, this investigation can be limited to a single-axis platform.

Fig. 1 shows the schematic and block diagrams of a single-axis platform. Our approach to the investigation differs from the usual one. We divide the block diagram into two parts: the first part—later called gyrodynamics—comprises the gyro, the gimbal, the armature of the motor, gears (if any), and the armature of the precession axis pickoff; the second part, the electronics, with the amplifiers, the shaping networks, the stator of the torque motor, and the stator of the precession axis pickoff. To clarify just where the divisions were made, the rotor and the stator of the torque motor and the

(*Continued on page 75*)

H = angular momentum of gyro, gr-cm-sec
d = viscous damping coefficient of gyro precession axis, gr-cm-sec
$D = n^2 D_M$ = viscous damping coefficient of torque motor (main part taken from steady-state torque-speed curve $\partial T/\partial \text{rpm}$), gr-cm-sec
$T = nT_M$ = torque applied by torque motor referred to ϕ-axis, gr-cm
T_M = torque applied by torque motor, gr-cm
n = gear ratio
$K = nK_M$ = torque motor coefficient referred to ϕ-axis, gr-cm/rad
K_M = torque motor coefficient, gr-cm/rad
a_0 = control coefficient of angle, 1 (dimensionless)
a_1 = control coefficient of rate of angle, sec
a_2 = control coefficient of rate of rate, sec^2
a_{-1} = control coefficient of time integral of angle, sec^{-1}

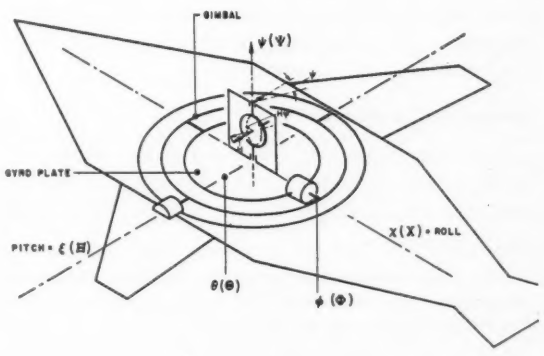

GIMBAL
ψ(Ψ)
GYRO PLATE
PITCH = ξ (Ξ)
χ(X) = ROLL
θ(Θ)
φ (Φ)
AXES OF THE GYRO PLATE = φ , θ WITH AMPLITUDES Φ, Θ
AXES OF THE AIRPLANE = χ , ξ WITH AMPLITUDES X, Ξ
PRECESSION ANGLE = ψ WITH AMPLITUDE Ψ

Fig. 2. Rectification effect.

Nuclear Electric Power for Space Missions

Terry W. Koerner and John J. Paulson

Jet Propulsion Laboratory, California Institute of Technology

THE FIRST PORTION of this paper covers present planning concerned with the spacecraft secondary power requirements for planetary, interplanetary, and lunar exploration. This planning and study are relatively independent of the means of getting the spacecraft to its destination, although electric propulsion must be included in the study to make it sufficiently complete for planning purposes. From the power requirement shown and the desired weights, the need for a nuclear power source is clearly indicated.

The second portion of the paper covers the use of electric propulsion for the final phases of propulsion to place the spacecraft at its destination. This portion attempts to show that there is more than just an improvement by the use of electric propulsion. There are certain missions where the need for electric propulsion is definite in that presently existing information shows it to be the only system capable of properly achieving the goals. By applying the same principles covered in the first portion of the paper on power and weight, we conclude without doubt that nuclear power is required.

Spacecraft Secondary Power

The use of nuclear sources for spacecraft secondary power will be largely dependent upon the mutual compatibility of the nuclear sources with the various space missions and the corresponding vehicles. In addition, the nuclear systems will probably be required to demonstrate sufficient performance advantages over other power systems to warrant the increased hazards associated with their use.

The space missions planned for the next decade are indicated in Table 1. Estimates of power system weights and power requirements for these missions have been included in order to indicate the approximate levels at which nuclear and "conventional" systems must compete. Values for the *Surveyor* and *Prospector* spacecraft are not indicated since these will be determined by the contractor.

The capabilities of various power sources are presented in Fig. 1, where weight is indicated as a function of power level. Probably the most significant power source parameter is the specific weight, or weight per unit power, since this determines to a large extent the performance of a system. Fig. 2 shows the specific weights of the previously mentioned power sources as function of power level. The values indicated for reactor sources do not include the weight of shielding; inclusion of shielding increases the specific weight by 20 to 100 percent, depending upon the radiation requirements. The figures shown for solar-powered equipment do not, with the exception of the Sunflower system, include the weight of energy storage equipment, which may account for 10 to 50 percent of the weight of a system.

Examination of Fig. 1 indicates that, on a specific weight basis, the crossover point from solar photovoltaic panels to the reactor sources occurs at power levels of from 0.7 to 3 kw, corresponding to weights in the range from 400 to 600 lbs. The crossover region indicated is based upon missions ranging from

This paper presents the results of one phase of research carried out at the Jet Propulsion Lab., C.I.T., under Contract No. NASw-6, sponsored by the NASA.

The authors wish to acknowledge the assistance in the preparation of this paper of the following members of the Jet Propulsion Lab.: Dr. David G. Elliott, Dr. N. R. Haynes, Paul Goldsmith, Dr. W. G. Melbourne, and Mrs. Evelyn W. Speiser.

"There is more than just an improvement by the use of electric propulsion. There are certain missions where the need for electric propulsion is definite . . . ."

Mars to Venus; for missions further out than Mars, the crossover point will occur at lower power levels. Note that the solar panel array which has been tentatively selected for *Mariner B* weighs about 200 lbs, while the SNAP-10 reactor source, which has roughly the same power capability, weighs about 350 lbs without shielding. The latter figure exceeds the present estimate of the total weight of the *Mariner B* power system, including batteries and converters. A likely alternative to the solar panels for *Mariner B* is a solar thermionic system, which holds promise of having a specific weight of about one third that of the solar panels. However, a considerable amount of development remains to be accomplished before such a system can be demonstrated to have achieved satisfactory performance.

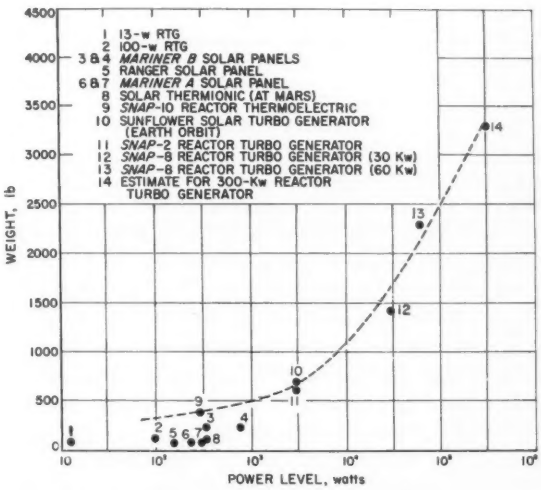

1 13-w RTG
2 100-w RTG
3 & 4 MARINER B SOLAR PANELS
5 RANGER SOLAR PANEL
6 & 7 MARINER A SOLAR PANEL
8 SOLAR THERMIONIC (AT MARS)
9 SNAP-10 REACTOR THERMOELECTRIC
10 SUNFLOWER SOLAR TURBO GENERATOR (EARTH ORBIT)
11 SNAP-2 REACTOR TURBO GENERATOR
12 SNAP-8 REACTOR TURBO GENERATOR (30 Kw)
13 SNAP-8 REACTOR TURBO GENERATOR (60 Kw)
14 ESTIMATE FOR 300-Kw REACTOR TURBO GENERATOR
WEIGHT, lb
POWER LEVEL, watts

Fig. 1. Weights of power sources vs. power levels.

Mr. Koerner received the B.S. (1951) and M.S. (1952) degrees in electrical engineering from the California Institute of Technology. In 1951 he joined the Jet Propulsion Lab. and for some time was associated with the design of test equipment for the Corporal missile. His later efforts were devoted to the design and development of test equipment for the Sergeant missile. In 1958 he became Group Leader of the Networks and Power Group with primary responsibilities for the development of Sergeant secondary power equipment and system studies related to electrical interference problems. In 1960 he was named Engineering Specialist and served as a Technical Adviser to the Guidance Engineering Section of the Guidance and Control Division. After completion of the Laboratory's program on the Sergeant missile, he continued as Technical Adviser to the newly formed Spacecraft Secondary Power Section, in which capacity he is presently serving.

Since he joined the Jet Propulsion Lab. in 1949, Mr. Paulson's career has included many areas in the aerospace field: In 1952 he headed a group in charge of all the electronic guidance and control equipment for the Army's Corporal missile, in 1955 he established the basic design philosophy for the Army's Sergeant guided-missile ground test equipment, and in 1956 he headed the design effort for the Inertial Guidance Platform for this Sergeant missile. By 1958 Mr. Paulson was appointed Chief of the Electromechanical Development Section in the Guidance Systems Components Division. In 1960 he was named Chief of the Advanced Propulsion Engineering Section at the Laboratory to provide the engineering effort necessary for use of nuclear and electric propulsion in the scientific exploration of space. A graduate of the California Institute of Technology (1941), with a B.S. in electrical engineering, Mr. Paulson served 4 years in World War II as a Navy electronics officer. He is an Associate Member of Sigma Xi and a member of the ARS.

The radioisotope thermoelectric generators (RTG) appear to be best suited for use where a small amount of power for an extended period is required, particularly where solar energy is not available or is available only on a relatively low-duty cycle. As an energy storage device, the RTG greatly exceeds conventional batteries in performance; at a 15-watt level, for example, the corresponding performance figures for a curium-fueled unit are about 3,600 whr per lb vs. 80 whr per lb. As may be seen in Fig. 2, the RTG units do not appear suitable for large power levels because of their relatively high specific weight. (*Continued on page 44*)

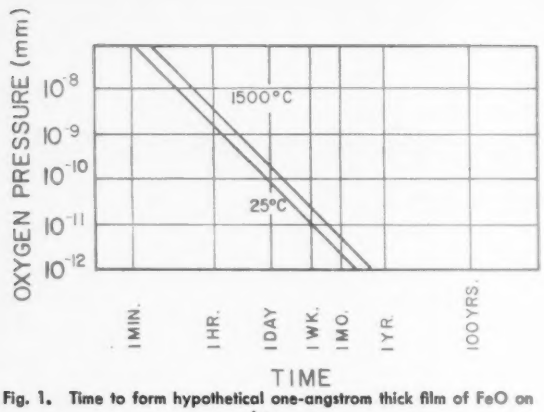


Fig. 1. Time to form hypothetical one-angstrom thick film of FeO on iron.

Mechanisms of

John L. Ham

National Research Corporation

Mr. Ham is engaged as research associate in metallurgical research on special melting techniques and the behavior of materials in ultrahigh vacuum at National Research Corporation. He has also specialized in metallurgical thermodynamics, diffusion in solids, and arc cast refractory metals.

WITH MOUNTING INTEREST in space technology, there is increasing incentive to learn whether materials will behave in space as they do on earth or whether unusual properties will be encountered. One of the major differences in space environment as compared with our environment on earth is the extremely low gas pressure. Even at an altitude of 500 miles the pressure is already reduced to the 10^{-9} to 10^{-10} mm Hg range. We have only recently learned to obtain pressures at this level in the laboratory, and no experimental information is yet available on the behavior of materials in this ultrahigh vacuum range.

However, some work has been done in recent years on materials' behavior in the moderate vacuum range of 10^{-5} to 10^{-6} mm Hg. Bowden,[1-3] Epifanov,[4] Levitskii,[5] Shahinian and Achter,[6] and Wadsworth and Hutchings[7] have reported evidence of changes in the coefficient of friction, fatigue, and creep rupture properties of metals. Explanations of these effects, while not wholly consistent, do in all cases relate to changes in surface films and to the rate of oxidation of metal surfaces. In evaluating the importance of testing in ultrahigh vacuum ranges of 10^{-10} mm Hg or lower, it is necessary to consider the differences in surface behavior which may occur in going from these previously investigated environments to ultrahigh vacuum.

Rate of Oxidation in Ultrahigh Vacuum

According to kinetic theory the total mass of any gas, passing in each direction through a fixed reference plane one square centimeter in area is given by[8] $G = 0.0583\ Pmm\sqrt{M/T}$, where G is the mass rate in g cm^{-2} sec^{-1}, P is the pressure in mm Hg, M is the molecular weight, and T is the absolute temperature.

This equation will be referred to as the Langmuir equation and obviously represents also (a) the mass rate of impingement on a solid surface and (b) the maximum rate at which a gas can escape a surface which is in chemical equilibrium with the gas at pressure Pmm. The Langmuir equation should be applicable for practical calculations of maximum gas evolution rates from surfaces so long as the surrounding total pressure is at least one decade lower than the vapor pressure or reaction pressure involved, since then a negligible number of the escaping atoms will return due to collision with other atoms.

However, for films only a few molecular layers thick or for surfaces covered or only partially covered with a single layer of the gas molecules or atoms the rate of transfer of molecules or atoms to or from the surface is more complex and depends on the crystallographic orientation of the metallic crystals (grains) at the surface.[9-11] The calculations to be presented below are concerned only with the maximum rate of formation or disappearance of films thick enough to obey the usual thermodynamic equilibrium relationships between pressure and temperature, on the surface of metals with small randomly oriented grains.

The encouragement and technical advice of R. A. Stauffer and W. Versluys in the preparation of this article are gratefully acknowledged.

Surface Removal From Metals in Space

Recent experimental work has indicated that surface properties can have an important influence on the behavior of materials in space.

Data presented by Gulbransen[12, 13] indicate that as the partial pressure of oxygen approaches very low values, the rate of oxidation of a metal approaches that corresponding to the rate of collision of oxygen molecules with the surface.

Fig. 1 shows the time to form a hypothetical one-angstrom thick layer of FeO on iron, plotted against pressure of oxygen, according to the Langmuir equation. The time is proportional to the density of the oxide divided by its molecular weight. The case is hypothetical since the thickness is less than that of a unit cell of FeO. At pressures in the 10^{-5} to 10^{-6} mm range a completely clean surface can be maintained for only a few seconds. If any new surface is formed by abrasion or by crack formation it will be effective for only a short time. At pressures which will be encountered in space such new surfaces will stay clean for days or weeks.

Examination of the pressure range which will permit simulation of space shows that pressures in the 10^{-10} to 10^{-11} range will, for the first time, permit tests in which a clean surface may be maintained during a test of reasonable duration.

Loss of Surface Films

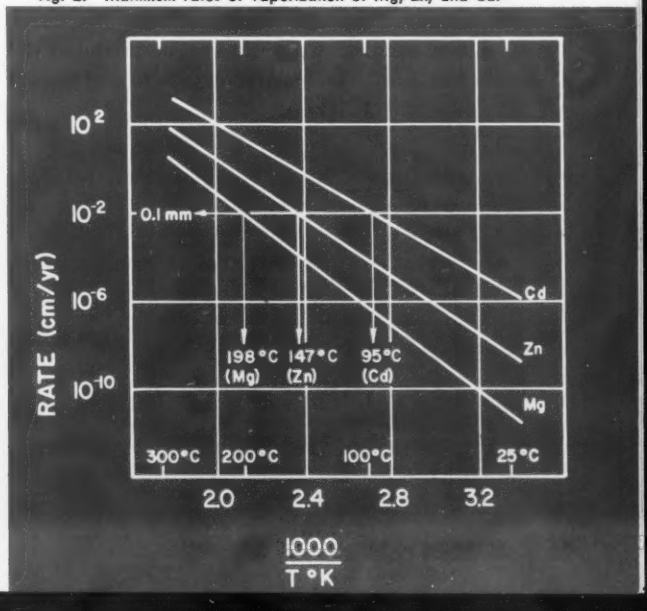
Now that it is possible to synthesize atmospheres so rarefied that no surface contamination can occur for long periods of time, the conditions under which a surface may be freed of its usual surface layers need to be studied. One very effective method of removal is wear. If two metal surfaces are rubbed against each other, the surface contamination will soon be removed and the two metallic materials will be in direct contact with each other. If this occurs in an atmosphere of 10^{-10} mm Hg or less, it is anticipated that severe pressure bonding will take place and that the increase in coefficient of friction will be even more spectacular than that observed by Bowden.

In addition to abrasion there are a number of other means by which surface layers may be removed from metals at very low pressures. The theoretical maximum rates for several of these will be calculated.

Metal Evaporation

Some metals are sufficiently volatile that the metal itself can evaporate to an appreciable extent at low temperatures given times of a month or a year. Magnesium, zinc, and cadmium are examples. If these metals are able to evaporate through their oxide coatings then the oxide coatings may be dislodged by this metal evapora- (*Continued on page 49*)

Fig. 2. Maximum rates of vaporization of Mg, Zn, and Cd.



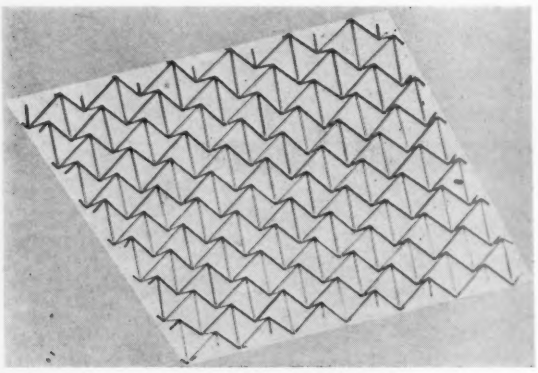


Fig. 1. Tubular truss core.

Development of an All-Welded Tubular

Bertram Klein

Convair (San Diego), a Division of General Dynamics

Mr. Klein is a design specialist, R&D, Structures Group, Engineering Dept., Convair, a Div. of General Dynamics, San Diego. Formerly, he was chief of structures, Solar Aircraft, Missile Dept. In that capacity, he was responsible for the design, stress and test on such projects as first-stage Minuteman, B-70 ducting, space APU systems, manufacture of large rocket cases, rocket nozzles, pressure vessels, thermal protection systems and Atlas missile subsystems. He received his B.A.E. and M.A.E. degrees from the Polytechnic Institute of Brooklyn in 1943 and 1945. From 1947 to 1950, he was assistant Professor, Purdue University. He is the author of more than 60 technical papers.

DURING THE PAST decade and a half great emphasis has been placed on the development of the practical use of sandwich structures. Originally, gluing was used as the principal method of attaching the faces and the core. At first, lightweight solid cores were used. As the art progressed, lighter and stronger cores were manufactured in honeycomb configurations. Recently, for high-temperature applications, the gluing has been replaced by furnace brazing. Attempts have been made in the past few years to produce an all-welded practical sandwich structure in order to eliminate excessive weight of brazing and its accompanying high cost. However, to date, a truly all-welded practical sandwich structure has not been made available. A truss-type core made of bent-up flat sheet has come into prominence of late. However, this core is not isotropic. Also, core weight is excessive for reasonable depth of structure. In addition, one is limited in skin gages for deep sandwiches. Thus, one is led to wonder how a truly all-welded sandwich structure can be produced that is efficient, too. The requirements to be met include:

1. Designing a true sandwich without using glue or braze.
2. Obtaining low-weight to stiffness and low-weight to strength ratio.
3. Maintaining a light skin weight.
4. Keeping overall costs relatively low.
5. Ascertaining low attachment weight.
6. Investigating and implementing the feasibility of double curved panels.

An important weight consideration is the hidden weight of attachments necessary to piece together sections of the sandwich structure and to beef up the structure locally where necessary to introduce local loadings. Such increases in weight should be held to a minimum in order to keep the overall weight of the entire structure low. For example, in actual practice, very heavy picture frames must be placed around lightweight sandwich panels in order to make them work. Also, solid slugs are necessary to affect the carrying of concentrated loads.

Another important consideration in the design of sandwich structures is the ability to construct curved panels, sometimes doubly curved panels. Such structures occur in the form of domes, spherical sections, and the like. The real difficulties of conventional gluing and brazing techniques show up when one attempts to build such doubly curved sections. The close tolerances cannot be met. Also heat treatable metals should be used in manufacturing brazed structures.

For the reasons explained, an effort was undertaken by the author in 1958 to manufacture a new type of sandwich structure. The resulting sandwich described below meets most of the requirements enumerated above.

Truss Core Sandwich

A novel sandwich structure having distinct advantages over existing sandwich-type structures is discussed. Design and fabrication utilizing this sandwich will help to overcome or minimize some of its seeming disadvantages.

The Structure

The structure advocated consists of three basic parts:

1. *A tubular truss core*—The core consists of an interlacing of very light miniature tubing all welded together as shown in Fig. 1.
2. *A chem-milled skin*—This skin has a pattern of triangles etched out of it. The remaining ribs comprising the sides of the triangles are essentially rectangular in cross section.
3. *A perforated skin*—This skin essentially is the same as the one in paragraph 2 except that the thin triangular skin is removed by perforation (Fig. 3).

Note the integral picture-frame edges in Figs. 2 and 3.

The steps in the fabrication of the structure are as follows:

1. The tube ribbons comprising the core are flattened and bent into Warren trusses. Then they are spot welded together in order to form a mutually orthogonal network of Warren trusses. Four individual straight tubular members meet at each intersection.
2. This core is spot welded to the perforated face using appropriate tooling to locate each node.
3. The final operation consists of regular spot welding of the aforementioned preassembly to the chem-milled skin using an eccentrically tipped electrode passed through the perforated skin.

Such a final assembly is shown in Figs. 4a and 4b. A set of relatively heavy tubes has been used as closing support members in this panel in order to insure the proper support for the edge flanges.

The structure described is believed to have the following attributes:

1. The core is relatively homogeneous in carrying shear.
2. The core is very light for its stiffness; also for its strength.
3. The core can be formed to fit compound curved surfaces relatively easily.
4. The core is free to expand under thermal loading.
5. The core thermal conductivity is very low.
6. No glue or braze is required to fabricate the structure.
7. Repairs or changes in the core can be made after the assembly is completed.
8. Very light perforated skins are possible if desired.
9. The weight of attachments can be kept low by use of integral attachments.
10. Deep sandwiches are possible, if desired.
11. Nearly complete fuel volume and possible baffle action is available when the structure is used as a missile skin.
12. Core splicing is (*Continued on page 54*)

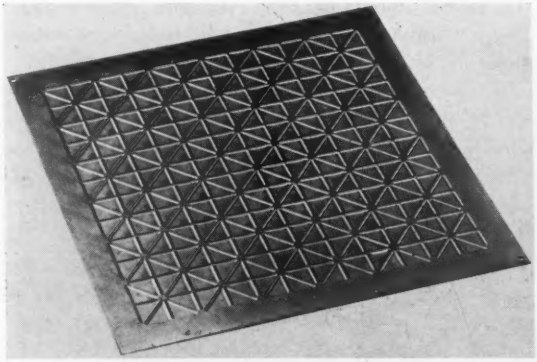


Fig. 2. Chem-milled stainless steel skin.

Aircraft Launching and Recovery Systems

Recent Advances and Their Potential Application to Commercial Aircraft—Part II

The last of a series of two articles describing the U.S. Naval Air Test Facility (Ship Installations) with details of arresting devices most promising for small field or emergency overrun use by jet transport.

Capt. William C. Fortune, AFIAS, U.S. Naval Air Test Facility (SI), Lakehurst

LAST MONTH'S ISSUE covered a general description of the U.S. Naval Air Test Facility (Ship Installations) and its capabilities for developing, testing and evaluating aircraft launching systems. Part II presents the work of the Test Facility in the field of arresting gear, the equipment used to stop the forward movement of aircraft landing on the decks of aircraft carriers or on airfields.

Since the first landing on a specially built platform aboard the U.S.S. "Pennsylvania" in 1911, arresting gear design has kept pace with the steadily increasing landing speeds and gross weights of modern aircraft. Because of the different sizes and types of carriers in use, with their different aircraft complements, arresting gear equipment varies in both configuration and capability with the carrier on which it is used. Basically, all employ deck pendants (wire rope) stretched across the flight deck, one of which is picked up by the tail hook, standard equipment in every U.S. Navy carrier plane. The wire rope is connected to hydraulic engines located below the flight deck wherein fluid friction absorbs the kinetic energy of each engaging airplane (Fig. 1). The aircraft is subjected to 3 to 6*g* deceleration on being brought to a stop in 200 to 300 ft.

In order to catch a rampaging aircraft if arrestment by deck pendant fails, various types of barriers and barricades have been developed to provide emergency or back-up methods of arrestment. Barriers for conventional single-engine propeller-type airplanes consist of multiple wire cables strung horizontally from deck edge to deck edge, connected to a shorter run-out arresting engine below decks. An adaptation of these, called the Davis Barrier, replaced the upper cable with nylon webbing and lifter straps to haul the lower cable up from the deck into the main gear after the nose wheel passed. This was designed for tri-cycle gear aircraft having jet propulsion or twin engines, but has not been completely successful. Barricades (Fig. 2), generally located forward and in the proximity of the last barrier, while more difficult to rig, have had much greater success. They consist of a group of nylon-fabricated webbing systems, combined as a unit, designed to ensnare jet airplanes and to transmit the forces to the same-type arresting engine.

Longer run-out devices (700 to 2,200 ft) are used for shore-based operations. This reduces the *g* loading to two or less, reducing the structural design requirements so that many airplanes can be adapted for their use. All "Century-series" U.S. Air Force Fighters are having tail hooks installed for emergency arrestment.

Testing and evaluation of recent arresting-gear designs in this realm indicate that recovery systems can be applied to commercial aircraft operations.

Over the past few years, the Navy has been pursuing an aggressive program in the area of land-based emergency overrun arresting gear. Five different types are in various stages of development, evaluation, and improvement. Each system embodies a different principle of energy dissipation. The oldest and most widely used is chain arresting gear. This system consists of two wire-rope cross-deck pendants which are connected to shots of anchor chain laid on both edges of the runway parallel to the runway center line. The principle of operation is to transfer aircraft momentum to the anchor chain and dissipate the chain energy through friction of the links on the runway surface. The chain weight is programed to control the

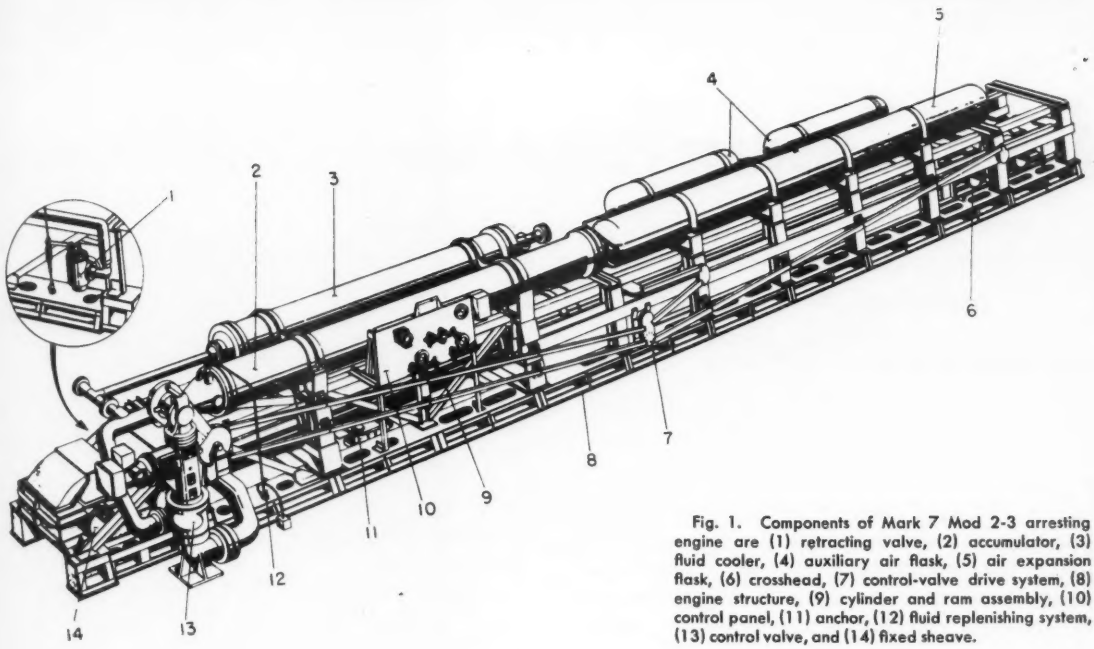


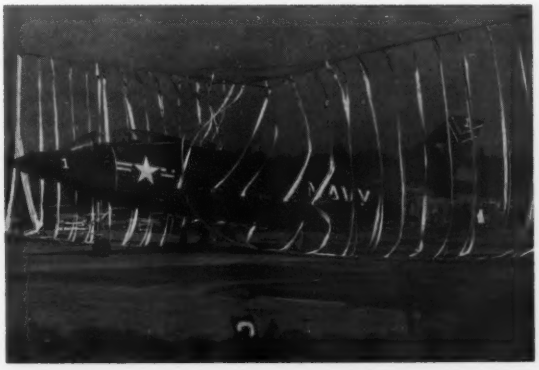
Fig. 1. Components of Mark 7 Mod 2-3 arresting engine are (1) retracting valve, (2) accumulator, (3) fluid cooler, (4) auxiliary air flask, (5) air expansion flask, (6) crosshead, (7) control-valve drive system, (8) engine structure, (9) cylinder and ram assembly, (10) control panel, (11) anchor, (12) fluid replenishing system, (13) control valve, and (14) fixed sheave.

retarding forces on the aircraft. The original cross-deck pendant configuration imposed an engaging speed limitation of 150 knots due to adverse cable dynamics causing high tensions in the pendants. Fig. 3 shows a new preformed or "shaped" pendant system developed by the Naval Air Engineering Facility in Philadelphia. On-center aircraft tests were completed on the "shaped" pendant system by NATF(SI) in October 1959, and off-center engagements are in process. Now designated as the E-5-1 arresting gear, the performance has been increased from 150 knots to 165 knots in the light- to medium-weight range while the heavy-weight range is limited by runout or energy absorption capacity. Fig. 4 illustrates a NATF(SI) aircraft which has just engaged the No. 1 cross-deck pendant of this gear. It is to be noted that the limiting runout of this system is 2,150 ft. This long runout is one disadvantage of this system which led the Navy into development of "water squeezers" (Fig. 5), another tail-hook catching device.

The water-squeezer type of arresting gear has been developed by the All American Engineering Company located in Wilmington, Del. It consists of a buried tube on each side of the runway, each tube containing a loose-fitting piston symmetrical on the upstream face. The symmetrical profile maintains the piston centrally located in the tube as it is pulled through by the cable attached to it. This cable is stretched across the runway, and caught by the airplane. The tube diameter can be continuously tapered as shown here or a step programing can be made by connecting straight tube lengths of decreasing diameters. The drag created, which is a function of the orifice area and the square of the piston speed, expends the kinetic energy of the aircraft. Retraction of Navy water squeezers is accomplished by utilizing a truck to pull a nylon retrieve rope attached to the piston. Retraction time by this method is approximately 25 min. Sophistication through the utilization of a pneumatic piston retrieve system could reduce this to a few minutes. By increasing the number of pistons to four being pulled through the tube, the engaging weight capability is raised to 50,000 lbs at speeds up to 160 knots. Maximum aircraft runout for both systems is 1,000 ft.

The simplest and most compact emergency arresting gear yet tested is the metal bender developed by Van Zelm Associates, Baltimore, Md. This arresting gear is dia- (*Continued on page 55*)

Fig. 2. Nylon-strap barricade ensnaring a test jet.



Aerospace Nuclear Power Safety Considerations

Lt. Col. Joseph A. Connor, Jr., USAF (MC)

THE RAPID DEVELOPMENT of aerospace nuclear power has presented the Atomic Energy Commission (AEC), the Department of Defense, and the National Aeronautics and Space Administration (NASA) with complex, new problems in nuclear safety. These nuclear power devices are mobile, operating both within and beyond the atmosphere. They introduce a possible source of new radioactivity to the earth, its atmosphere and oceans, to other solar system bodies, and to space at large.

This paper analyzes the probable amount, dispersion, location and biological significance of radioactivity that may be released. It discusses: aerospace nuclear safety criteria; measures for assuring safety; a program of testing; and increasing operational flexibility with advances in technology.

Basic Problem Areas

1. *The Over-All Radioactivity Release Problem*

At the start, to visualize the total picture, let us look at all of the aerospace nuclear power systems, and briefly review the main problem areas. Each of the specific projects (aircraft, ramjet, rocket, and auxiliary power) has a particular set of radiation safety problems. Broadly, these concern: (1) release into man's environs, or into space, of fission products or specific isotopes during normal operations, or under accidental conditions; (2) shielding of air crews, maintenance personnel, and the general public from direct radiation; (3) selection of test sites and ranges; (4) launch pad failures; (5) preorbital failure of space vehicles; and (6) random return to earth of intact or partially intact devices, as a result of failure to burn up on re-entry, or of deviations from programed trajectories.

It has been calculated that the radioactivity that could be released by nuclear-powered devices sufficient to meet all space requirements foreseeable by 1980 would make a minor contribution to the world background level. Our present two test launching sites (Cape Canaveral, Fla., and Vandenberg AFB, Calif.) could handle the maximum credible releases from both SNAP and Rover systems. Through special design features and devices that promote fast burnup, it is expected that burnup would result for nuclear-powered vehicles that might fall outside the flight range areas. This conclusion would remain valid even assuming a parallel effort elsewhere matching that of the United States.

2. *Analysis of Basic Problems*

In analyzing the possible hazards to people from aerospace nuclear power sources, there are three basic considerations:

(a) The potential contribution of radioactive materials (normal operations or accidents) to the atmosphere, assuming a reasonable dispersal after release.

(b) The local amounts of direct radiation or release of radioactivity from the use of these devices.

(c) The areas of the world which might experience this localized radioactivity.

3. *Atmospheric Distribution of Radioactivity—Biological Factors*

The distribution and transport of atmospheric contaminants from space nuclear power can be roughly estimated based on information now available from weapons test debris, industrial pollution,

Col. Connor is Chairman, Aerospace Nuclear Safety Board, Division of Reactor Development, AEC. He received his M.D. degree from George Washington University in 1943 and two years later was graduated from the USAF School of Aviation Medicine. Since then, he has filled many executive positions, as assigned by the Office of the Surgeon General, USAF. immediately prior to his association with AEC's Division of Reactor Development in 1958, Col. Connor was Commander, 509th (SAC) Tactical Hospital, and Director of Professional Services, Walker AF Base, Roswell, N.M. He has done postgraduate study in Nuclear Medicine and Radiobiology and is former Acting Chief of Aviation Medicine, USAF.

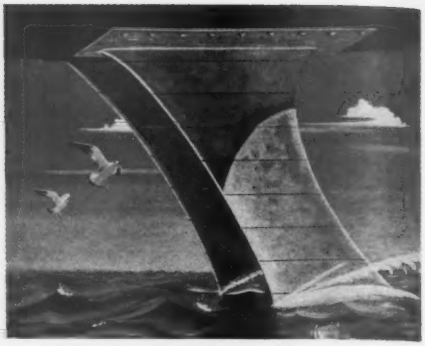
Photograph of Ursa Major and surrounding skies from the Mount Wilson and Palomar Observatories.

Analyses are given of probable amount, dispersion, location and biological significance of radioactivity released. Discussion includes aerospace nuclear safety criteria, measures for assuring safety, a testing program, and increasing operational flexibility with technology advances.

and the science of meteorology. As examples of the role played by basic factors in the atmosphere, the following illustrations can be used. The surface of the earth has an area of approximately 518 million km^2. One megacurie (10^6 c) of radioactivity deposited uniformly over the earth's surface would have a surface concentration of about 2 millicuries per km^2. The density of the air decreases continuously with increasing altitude from approximately 1.2 grams per liter at sea level. The total mass of the atmosphere is 5.2×10^{21} grams. Thus, one megacurie of radioactivity mixed uniformly into the entire mass of the atmosphere would have a sea level concentration of approximately 0.2 $\mu\mu$c per m^3, or 5 disintegrations per minute per 10 m^3 (as compared with the same volume of normal air, which has a background count on the order of 100 disintegrations per min). Present background of polonium-210 averages 1.3 $\mu\mu$c per gram in the top 2 in. of soil (from natural decay of uranium and radon). One SNAP unit, if fueled with 2,000 c of polonium-210, after burn-up on re-entry and assuming uniform distribution over the earth's surface, would add 0.00006 $\mu\mu$c per gram to the existing natural source (a factor of 1/20,000).

The aforementioned uniform distribution is, of course, an assumption. Factors affecting the distribution of debris in the atmosphere and on the earth's surface include many complex mixing processes. Concentrations, in general, will be greatest near the point of injection at short times after release, and will gradually become lower and more uniform. The fate of debris released into the ocean will depend on the rate and depth of release and character of the material, and will be affected by ocean currents, turbulent mixing processes, and biological transport processes.

The biological radiation hazards associated with aerospace nuclear energy are of two major types: (a) external exposure to neutrons, gamma and beta rays, and (b) internal exposure to alpha, beta and gamma emitting isotopes. External radiation exposures can arise from the deposition of atmospherically dispersed radioisotopes. Internal deposition can occur via (*Continued on page 58*)



In the Wake of . . .

"Hydrofoils at the Crossroads"

Practical?

◈ The subject of hydrofoils has been receiving more and more attention since the Maritime Administration and the U.S. Navy have undertaken to construct operational craft. The authors present a good summary of early attempts to apply the principle of hydrofoils to boats. The limited success and considerable mechanical difficulties which were encountered prevented a more rapid development. Just as with early aeroplanes, there appeared to be many ways in which a hydrofoil could be used. Some of the photographs in the paper indicate that, while the principle may be sound, the ungainly nature of the boat would discourage practical applications. The need to retract these hydrofoils when docking a boat has also contributed to problems of arriving at a workable design. The final acceptance of a hydrofoil boat will depend on the designer's ability to come up with a practical marriage of the foils and boat or ship at a reasonable cost.

In the interest of completeness, it should be mentioned that Mr. Baker, who designed and built the highly successful "Hypockets," also built another submerged foil boat "Hytail." This remarkable craft has an autopilot composed of mechanical linkages that takes the place of the complicated electronic type.

The very successful European Supramar hydrofoil ferries have compiled a record which shows that the basic principle will work. The problems that exist should be a challenge to those whose concern it is to carry out the research program mentioned in the paper.

John Bader
Hydrofoils, Inc., San Diego, Calif.

Useful

◈ As a record of the status of the hydrofoil art, as an assessment of the range of usefulness of hydrofoils, and as a clarification of high-speed design problems confronting the industry, I have found the paper a much needed guide for future development planning—i.e., a true guidepost at the "crossroads."

In the paper under the subject of Hydromechanics one method of raising the speed at which serious cavitation appears is mentioned. I would appreciate knowing how much the propeller wake passing over the hydrofoil, in the configuration shown in Fig. 10 of the paper, lowers the speed at which serious cavitation appears.

John G. Baker
Baker Manufacturing Co., Evansville, Wis.

Problems

◈ Lt. Comdr. Nelson (see NOTE) has provided a clear review of the Navy hydrofoil program and some insight into the reasons for the present direction of this program. He has identified many of the significant technical problem areas and has described the work being conducted which should lead to some resolution of these problems. I would like to amplify on some of his remarks in an effort to redefine what we at Boeing see as the crossroads today.

PC(H)

Besides the many technical problems presented by Lt. Comdr. Nelson, there are also many operational problems and unknowns associated with the application of hydrofoil craft as a military weapon. Answers to many of these unknowns, so essential to the development of fully effective hydrofoil systems, will become available through operation of the PC(H).

"Hydrofoils at the Crossroads," published in March, has been lauded both as to quality and as to its service in the realm of technical communications. Hopeful that thoughts on the interesting "marriage" of hydro- and aerodynamics may be stimulated further and that two industries may reap benefits from this still new union, AEROSPACE ENGINEERING *presents herewith nine discussions on "Hydrofoils at the Crossroads." As a denouement, there is a reply from the authors, Capt. James J. Stilwell and Lt. Comdrs. Perry W. Nelson and William R. Porter of the Navy's Bureau of Ships.* ● The Editor

Boeing enthusiastically supports this program. We believe the basic design of the craft is sound and Boeing is about 20 percent complete on the program to date (January 1961). We are on cost and schedule and fully expect to deliver a solidly designed, reliable craft to the Navy in mid '62. As the design develops, we are working closely with the Navy to incorporate many design improvements to achieve the best operational craft in the available time period.

Military Application

The military operational application of hydrofoil craft is an area touched on only briefly by Lt. Comdr. Nelson, due to the technical development approach of the paper. Thus, one area which we believe to be of paramount importance was not emphasized. This area is the effect on the system operational capability of coordinated military subsystem developments and their proper integration in the basic design of the craft. The manner in which these developments are guided and the results achieved should and will greatly influence the future design of hydrofoil craft. Sonar development is most certainly of the utmost importance to successful adaptation of hydrofoil craft to anti-submarine warfare. The effects of noise generation, transmission and radiation on the craft's own sonar and on other units in the area are largely unknown and require detailed investigation. Here again, problem solutions affect the basic design.

The integration of the basic craft and its subsystems into a near optimum effective operational unit is an area where the aircraft industry has had much experience. Military aircraft and missile requirements are believed to have required systems integration well beyond that normally associated with naval ships. While the physical items may be different, the disciplines developed in the industry are directly applicable to the design of hydrofoil craft where complete integration of the system is as important to success as in aircraft.

Aero-Marine Relationship

A. *General*—To approach the subject of the aero-marine relationship, let me first state that we do not consider the aeronautical engineer and his aerodynamic specialists widely separated on the spectrum of design philosophy from the naval architect and hydrodynamicist.

The "wild blue yonder" approach which the author attributes to the aircraft industry might stem from observation of the far reaching look at possible systems developments continually taken by the aircraft industry to establish the required direction of major research efforts. The attainment of major advancements has been possible through *heavy* application of research to obtain major improvements in the state-of-the-art of many related fields rather than through a basically unconservative engineering approach. The marine field has been somewhat hampered by a proportionate lack of adequate funds for research in advanced areas.

B. *Materials*—For aircraft structures, for example, the design loads conditions are generally better known than those relating to ships, and thus permit greater utilization of the material allowables on a rational basis. Therefore, the factor of safety of 1.5 commonly used for aircraft design may, (*Continued on page 61*)

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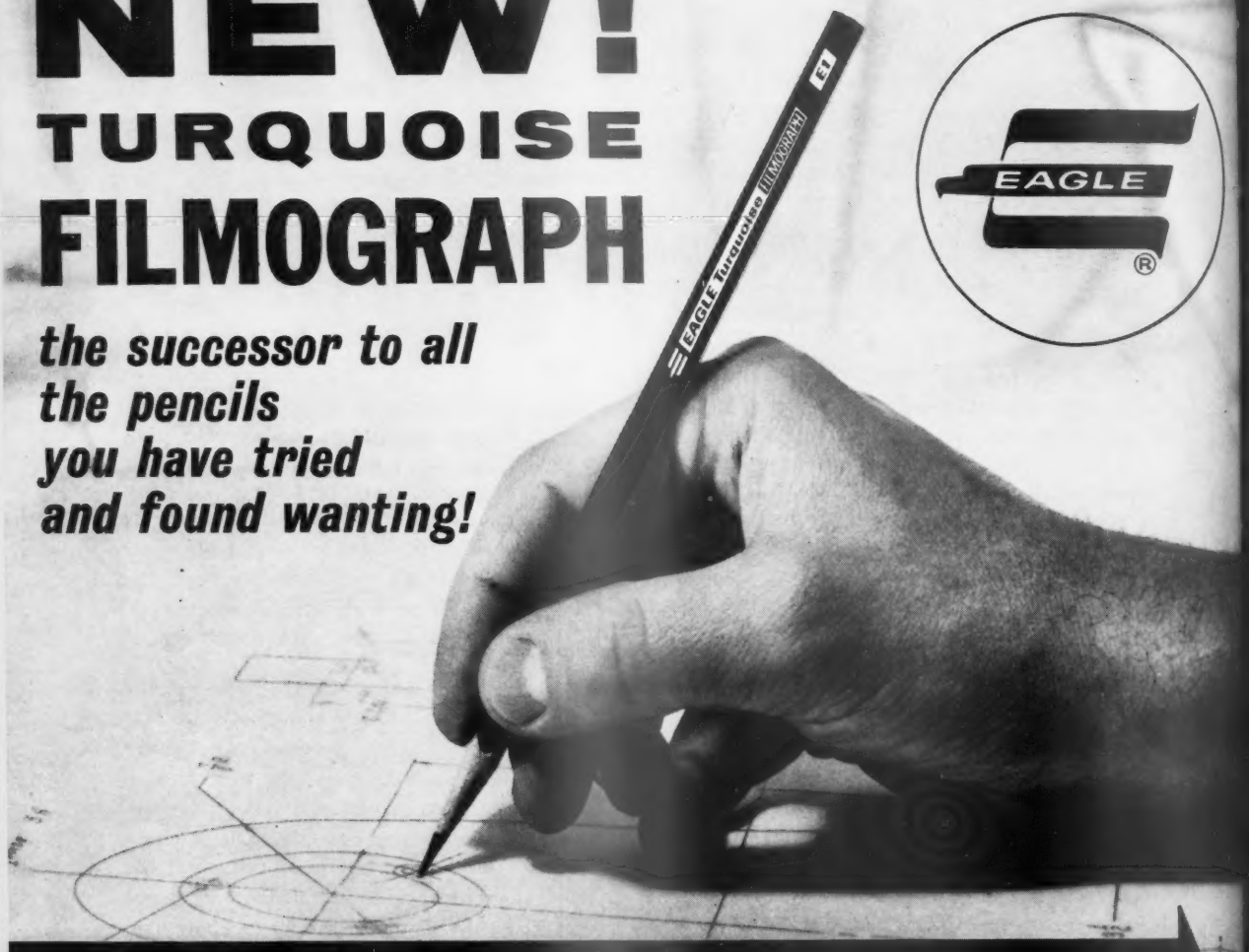

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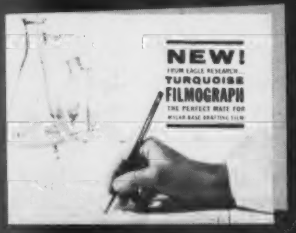

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We Have to Communicate (Continued from page 13)

how well we can communicate our thoughts to others and how well we can receive theirs in turn. Thus, even if you are the most brilliant, hard-working, capable person alive you are rather worthless to yourself and to the community as a whole unless you can communicate your discoveries, decisions and brilliance to others. No company wants or needs the genius who cannot provide an application for his thoughts or who cannot convince management that they ought to do the correct thing at the proper time. No good is achieved when you alone know what is right, you must be able to implement your decisions and, to do this, you must communicate convincingly and at the right time.

You and I have seen textbooks and technical articles which seem to be written to confuse the reader. It is very easy to write such a book or paper. It is far harder to write one which can be understood by many people, particularly those unfamiliar with the topic in the first place. There do exist some who seem actually to try to write such a way as to confuse and to bore the reader (this can be done without trying). Indeed, I have been told that there is a professor at a prominent eastern university who states that anyone who writes an understandable text is incapable of performing research. Personally, I think that anyone who understands his topic ought to be able to explain it to others even if he has to do a little extra work in the process. You will forgive me if I say I believe that the person who stipulates this or that to be beyond anyone's comprehension but his own is more than likely a fraud or an extreme neurotic. In any case, I would not care to have him around since he can do no good unless he learns to communicate and, certainly, I would not be able to trust his judgment. It may be that I am old fashioned, but I think I share with most other people the thought that "the proof of the pudding is in the eating." I think there is a desperate need to communicate and the more complex the subject matter the more time and effort are required to do the job properly. The ultimate judgment as to the worth of this effort lies only in the results produced.

No one can ever communicate perfectly at all times or with all other people; we must do the best we can, but this is not a matter to be casually approached. It takes much hard work to prepare even an adequate paper or other presentation, but without this hard work we can expect little. Recognition of this fact is far more important than either good grammar or perfect punctuation. In other words, since it involves work to write even reasonably well, it is necessary that the writer have some motive for writing in the first place. In this short paper, I have attempted to make the point that our progress, either as individuals or as a Nation, is irrevocably tied into our ability to communicate. Moreover, it seems to me that we have a *duty* to communicate. The failure of an otherwise competent technically trained personality to learn to communicate can neutralize every one of his good points and, furthermore, alienate those with whom he should learn to cooperate. As we learned merely to talk when we were young we now must seek, on the highest level, the ability to communicate with maximum effectiveness.

At this point, it would be satisfying to set forth a set of rules which could guarantee effective communication, but communication is a highly individualistic thing and rules alone carry no promise that, if followed, success will be insured. So, rather than call the following a set of rules, I think it better to call them guideposts.

Proper Motivation

You must have a reason to communicate and you must have something which needs saying. Sincerity and the courage of your convictions are mandatory to avoid weasel words, obscure development and an excessive number of qualified statements. If definite conclusions cannot be derived, motivation is questionable.

There exists an archaic notion in some circles that one must continuously publish to achieve professional stature. This notion has given rise to many papers which communicate little or nothing. Such papers are not communications because their motivation is questionable. In some cases, authors reacting to this pressure have published numerous rewrites of the same paper in various journals. This practice and the extreme care taken by the authors to avoid criticism of such papers produces a negative result because really worthwhile papers may be lost in the shuffle. Moreover, it directs attention away from fundamentals and produces preoccupation with minor detail. Remember, there are no absolute physical facts so that extreme concentration on minor points may not be compatible with the nature of real or physical problems.

Thus, while one should not disparage the motivation provided by the desire for fame and fortune, by itself, and unsupported by sincerity, it cannot provide for adequate communication. Motivation must be sincere and proper.

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Know and Consider Your Audience

As a teacher, I have seen engineering students frequently left cold by a problem treated in the abstract style of pure mathematics while the person, used only to abstract thinking, is likely to be annoyed, on occasion by the more physical or intuitive approaches. The humanist in turn, may be unreceptive to any approach which is somewhat deterministic in nature, since his experience may have taught him that there are always two sides to a coin. It is very difficult, if not impossible, to satisfy a universal audience with a single approach. Thus, the communication must be prepared to suit the group to whom you most need and want to impart information.

If the group you are addressing is nontechnical or perhaps inexperienced in your field, you must remember that some of those factors which seem obvious to you may be very obscure to your audience and they will not appreciate your making them jump over hurdles which could have been removed by a little more effort on your part. Because numerous specialists develop their own shorthand way of saying things (shop talk), there is need for a definition of those terms which may be alien to the audience. If the specialist is addressing people not as familiar as he with the subject matter (which nearly always is the case), he must introduce his topic in nontechnical or nonspecialized terms. In technical literature, there are numerous examples of papers which could really have had a significant impact if they had just been read and understood by the right people, but these people never read them and never realized that they should have read them. It is a mistake to think that busy people can or will take the time to examine a communication unless that communication is sufficiently definitive to arouse their interest initially and, then, sufficiently clear to hold this interest until the message is complete.

You must know your audience and consider their interests as well as your own. Seldom will you have the advantage of a really captive audience because not even a teacher can depend on having one. An audience cannot be forced to listen even if they are forced to attend and to stay awake.

Part of your consideration for your audience is reflected in your choice of style.

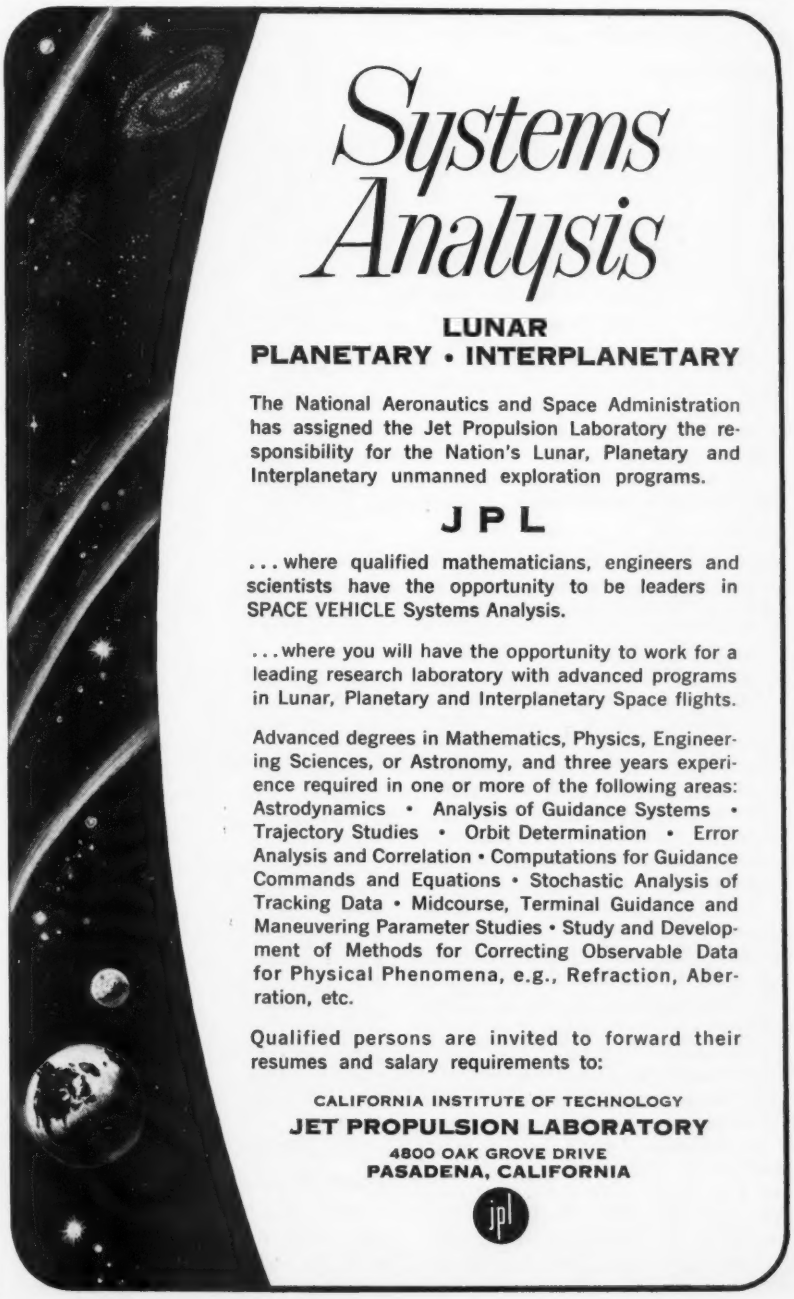
Style

If you were to draw up a legal document you would need to consider, very carefully, the legal interpretation of each of your words and statements. You would be concerned with a problem in legal semantics and would need to know the legal meaning of your expressions. Because of this fact, one legal document resembles another and the set of characteristics which cause this resemblance can be referred to as legal style.

I suspect there are few people who read legal documents for their own entertainment; the style is hardly conducive to this. Similarly, relatively few people read technical communications for purposes of pleasure. Partly this is a result of the style adopted by some technical writers; partly it is a result of the nature of the subject matter. Nothing can be done about the topic, but something can be done about the style: enough to make almost any topic interesting. Technical writing need not be abysmally dull; it need not be stilted, or pompous, or excessively complicated. You don't need to say "in order to" when you mean "to." You don't need to use ten words when two will do, but on the other hand you do need to use a sufficient number of adverbs and adjectives to make your meaning completely clear. By no means do you need to use the passive voice; the active voice is much more definitive and the sentences may be made shorter.

It may seem more modest to say "the author believes," but it is far less pompous to say "I think."

Technical writing (or you might consider it semitechnical) can be fascinat-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ing reading. There are many cases where it is, but one has to see this to believe it. E. S. Deevey's article[1] is a truly magnificent example of what can be done, and is recommended reading.

"Guide for Air Force Writing"[2] and other booklets on technical writing present a number of excellent examples of good and bad style, and I recommend that you read them if you have the chance; if not, keep in mind your real need to communicate and common sense will adjust your style of writing to the job at hand. Style is never a fixed thing, and unfortunately I can think of cases where you might be more effective in presenting your case if your style conforms to a standard lower than you might like; consider your audience.

Organization

I do not think you need to list carefully, on paper, all of your thoughts before preparing a presentation; this is too rigid a procedure. However, I do think you need at least some mental plan of action which, of course, you can and should modify as you go along. It is important to have your thoughts organized sufficiently to avoid losing track of the message you plan to convey, to whom you want it conveyed, and how you propose to prove and sell your technical points. Failure to keep your direction in mind, or failure to determine the direction in the first place, will most certainly produce some chaos.

Rewriting the Presentation

Since writing is hard work, it is easy to put it off or leave it incomplete. For this reason, the rough draft should be prepared very rapidly to make sure the major thoughts, at least, are set down before the inspiration vanishes. You should consider the rough draft only as a nucleus from which the final presentation is to be developed. Don't hesitate to change it and, by all means, be critical of your own effort. If you have the time to set the draft aside for a while, you will be surprised at how much improvement can be made on a rewrite if you have waited long enough to have forgotten your specific words.

A good presentation or a good book may have been rewritten several times before its release and some sections may have been altered a dozen times.

Do not hesitate to rewrite and do not hesitate to discard your own work if it is not adequate. In reading draft copy, keep in mind that if you stumble at any point along the way, you should rewrite the offending section.

In conclusion, I could dwell at great length on the topic of writing technique, but I think that this would bore you. Also, excessive detail would defeat the purpose of this paper which is to underline the need of our technical groups to improve their communication with others and to communicate decisively, properly, and at the right time. I sincerely believe that this is of utmost importance to our national welfare and to all of us in a more personal way. I think the motivation to communicate effectively is the single dominant factor leading to adequate and proper presentation. If the motivation is present, the rest will follow in time. But, I believe there is no time to waste and I earnestly hope that those of you who have reached this point in the paper will have grasped the idea that there is a need to write and that thoughts or ideas either left unexpressed or improperly expressed are essentially worthless. There is a real need for good technical expression not only in technical journals, but also in the evaluation of our national picture and the international scene. Technical people cannot afford to remain silent on major issues while others who may not have the facts available to them proceed to make the decisions. I do not think it is impertinent for us to try to do the best job we can in applying technical skill to the major problems of the day, even though this requires attention to issues rather than details. Finally, I do not consider this paper a perfect job of writing so please follow the old adage "Do as I say, not as I do."

References

[1] Deevey, E. S., *The Hare and the Haruspex*, American Scientist, Vol. 48, No. 3, pp. 415–430, Sept. 1960.

[2] Anon., *Guide for Air Force Writing*, Air University, Air Command and Staff School, Maxwell Air Force Base, Alabama.

Nuclear Rocket Stages (Continued from page 15)

both nuclear vehicles indicate a substantial performance increase at the higher power levels over the all-chemical Saturn. However, practical vehicle design limitations, arising from the relatively large nuclear stage tankage volume, would tend to restrict the useful nuclear engine power level for Saturn. Since the density of the monopropellant used in the nuclear stage, liquid H_2, is only about 1/5 that of the chemical bi-propellants, O_2/H_2, the use of optimum nuclear stage propellant loadings at high thrust levels are not generally compatible with the boost stages. Therefore, as an example, if a Saturn/nuclear vehicle design is chosen so that the total vehicle's fineness ratio is kept within rather conventional limits, say less than 15, a nuclear third stage configuration with a propellant loading of about 100,000 lbs of H_2 is indicated. A vehicle of this type is shown in Fig. 4. The appropriate nuclear thrust level for such a vehicle is about 75,000 lbs. Using an Isp adjusted to ideal conditions Fig. 2 indicates a reactor power of about 1,500 mw.

A nuclear stage of this size, providing over one half of the velocity requirement for an escape mission, would permit a soft-landed payload on the lunar surface approximately three times the weight of that of its all-chemical counterpart. While this would constitute an attractive increase over the basic Saturn and might be attractive for certain operations, it would still not permit manned lunar landings with return capability.

Space Missions

The following discussion indicates how orbital refueling could greatly extend the capability of Saturn/nuclear vehicles. The previously described nuclear third stage with a fuel tank capacity of approximately 100,000 lbs would be adequate, with refueling, for performing several types of attractive manned lunar missions. The Saturn boosted nuclear stage would power itself and a chemical terminal stage with a manned capsule into a low earth orbit; thus the space vehicle would arrive in orbit intact with no vehicular assembly operations necessary. After being refueled in orbit by Saturn boosted tankers, the gross weight of the entire vehicle would approach a maximum value of about 100 tons.

One early attractive mission for a vehicle of this type might be a low altitude lunar orbital reconnaissance flight. The nuclear stage leaves earth orbit and powers a 50,000-lb chemical O_2/H_2 stage into a 50-mile altitude circular lunar orbit with a 30,000-lb manned capsule. After a predetermined stay time in lunar orbit, the chemical stage could be used to power the capsule back into either an earth orbit or into a low velocity re-entry descent. The chemical stage would provide adequate capability to abort the mission in the event of a nuclear stage malfunction. A breakdown of vehicle weights and mission velocities is shown in Table 1. A sketch of the mission profile is shown in Fig. 5.

Another interesting mission, the manned landing and return, could conceivably be accomplished in the following manner. The nuclear stage powers a chemical stage, IRFNA/UDMH, with a 10,000-lb manned capsule from earth orbit to the lunar surface. The nuclear stage could slow the vehicle to landing velocity and still be jettisoned a safe distance away from the landing area just prior to final let-down; the final maneuvers and landing would be performed with the chemical stage. After a brief

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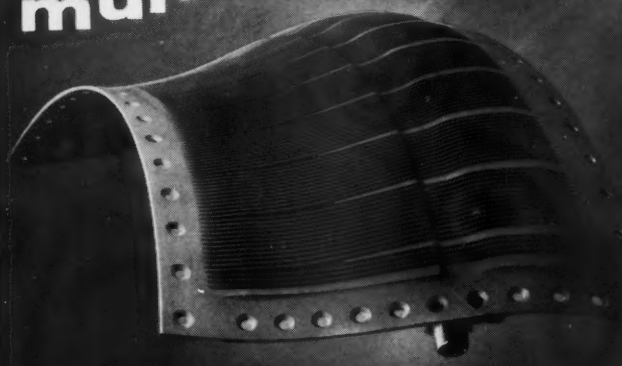
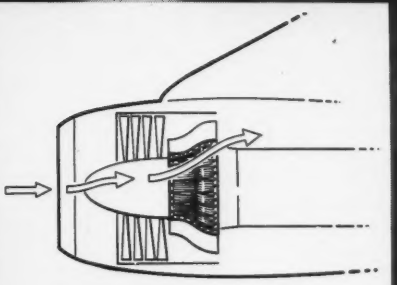
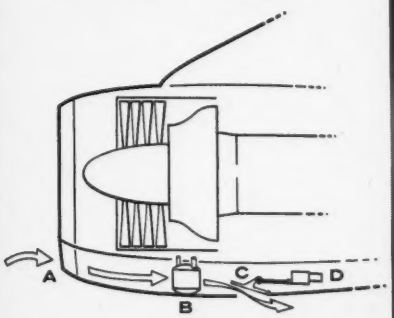


heat exchangers

reduce size, weight and drag...



Multicontoured oil cooler is section of fan exhaust duct



Conventional oil cooling system includes: A. Duct B. Heat exchanger C. Door D. Actuator

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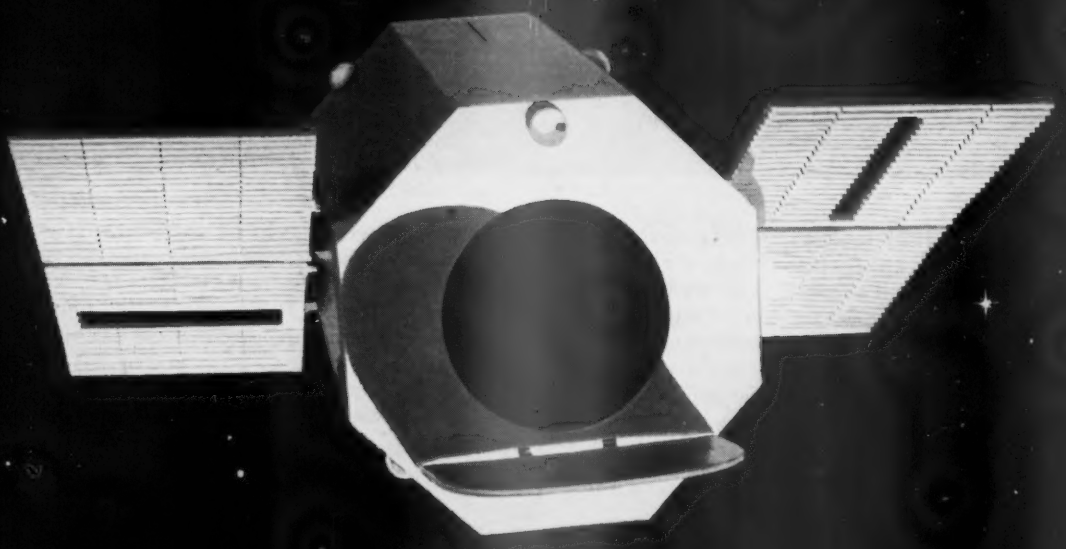

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Advanced ideas grow into reality at . . .

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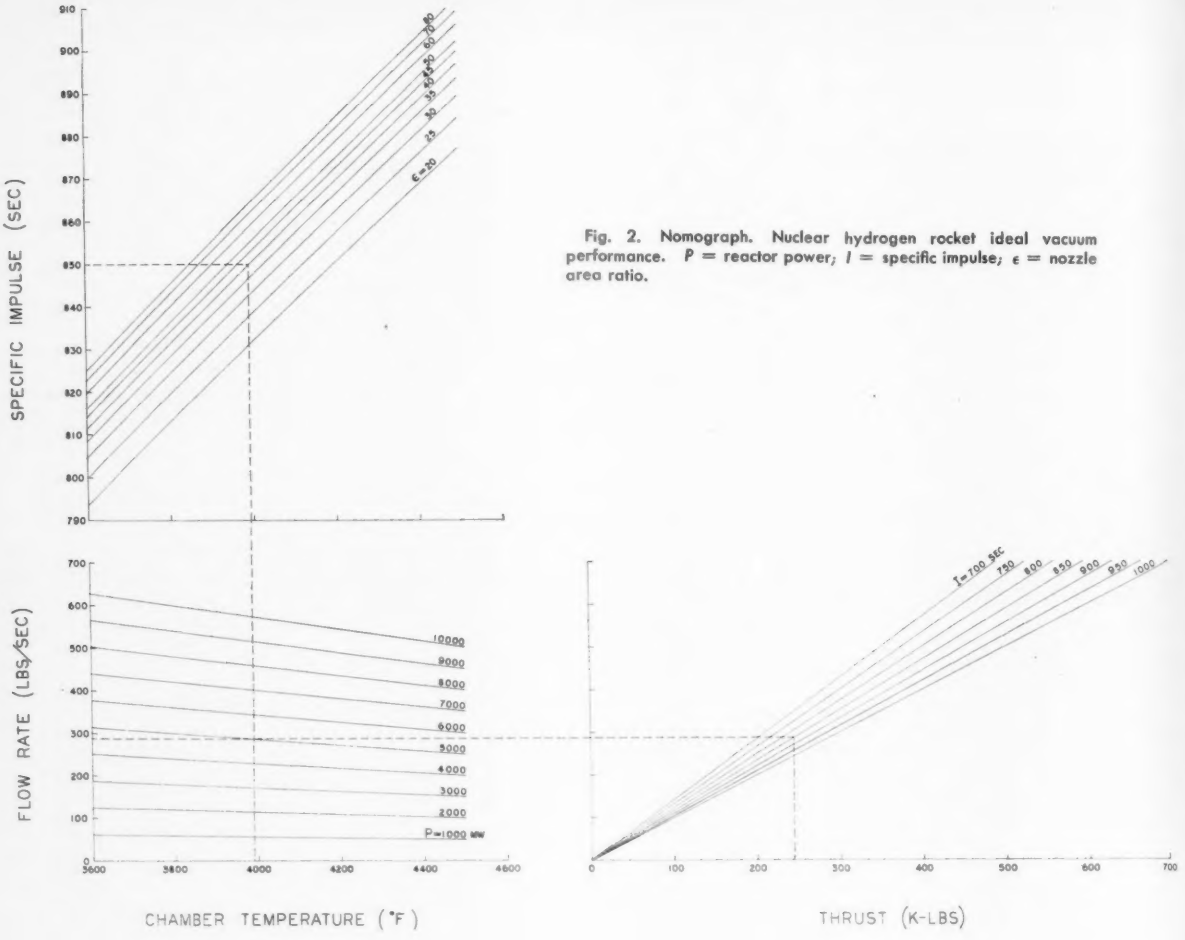

Fig. 2. Nomograph. Nuclear hydrogen rocket ideal vacuum performance. P = reactor power, I = specific impulse, ϵ = nozzle area ratio.

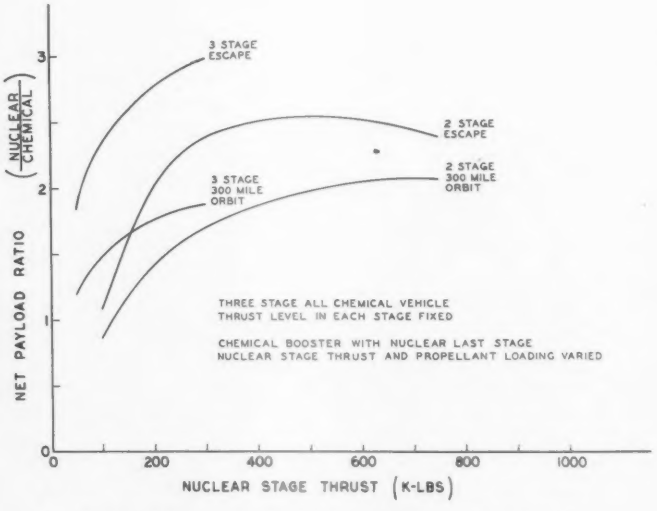

Fig. 3. Net payload ratio of Saturn nuclear to chemical vehicles.

Fig. 4. Saturn nuclear space vehicle.

stay, escape from the lunar surface for return to the earth would be accomplished with the chemical stage. A breakdown of the mission is given in Table 2 and a mission sketch shown in Fig. 6.

Growth Potential for Deep Space

By attaching additional fuel tanks to the basic nuclear vehicle in orbit, the initial gross weight could be increased and the payload increased, up to the point of diminishing returns. A suitable initial thrust/weight ratio appears to be roughly 1/4 (reference 1). By clustering of the stages which are self-powered into orbit, the thrust/weight ratio could be maintained as the gross weight increased to any desired magnitude thereby providing unlimited payload growth potential for lunar class space missions. Still later, by parallel staging the clustered nuclear vehicle, favorable overall mass ratios with flexible staging combinations would appear possible so that deeper space missions and fast interplanetary flights could be achieved (reference 2). Space vehicles using this approach for lunar

Fig. 5. Manned lunar orbital reconnaissance mission.

Fig. 6. Manned lunar landing mission.

and interplanetary missions are represented in Fig. 7.

Conclusions

A nuclear rocket of 1,000 to 2,000 mw used in conjunction with Saturn would constitute a space transportation system of great flexibility and growth potential. A nuclear rocket third stage on Saturn would increase the payload capability for orbital and escape missions by a factor of $1^1/_2$ to $2^1/_2$ times that of the all-chemical vehicle. In succeeding phases of development the nuclear third stage with a chemical terminal stage would allow, with orbital refueling, certain attractive manned lunar orbital reconnaissance missions and lunar landings with return capability. In still later phases of development by clustering of the individual nuclear stages in orbit in a parallel staging arrangement, deeper space missions including manned interplanetary flight could be achieved.

Table 1. Manned Lunar Orbital Reconnaissance Mission

Weight Summary	
Initial Gross Weight in Earth Orbit, lb	200,000
Cutoff in Lunar Orbit, lb	110,000
Chemical Stage, lb	50,000
Manned Capsule, lb	30,000
Nuclear Stage, Empty, lb	30,000
Cutoff Weight at Re-entry to Earth, lb	40,000
Chemical Stage, Empty, lb	10,000
Capsule, lb	30,000
Mission Velocities	
ΔV, Escape from Earth Orbit, 60-Hour Transfer (nuclear), fps	11,500
ΔV, Braking into Lunar Orbit (nuclear), fps	4,000
ΔV, Return from Lunar Orbit and Braking, fps	9,500
Re-entry Velocity, fps	30,000

Table 2. Manned Lunar Landing Mission

Weight Summary	
Initial Gross Weight in Earth Orbit, lb	175,000
Weight Soft Landed on Lunar Surface, lb	75,000
Nuclear Stage, Empty, lb	30,000
Chemical Stage, lb	35,000
Manned Capsule, lb	10,000
Cutoff Weight at Re-entry to Earth, lb	15,000
Chemical Stage, Empty, lb	5,000
Manned Capsule, lb	10,000
Mission Velocities	
ΔV, Escape from Earth Orbit, 60-Hour Transfer (nuclear), fps	11,500
ΔV, Braking and Landing (nuclear and chemical), fps	10,000
ΔV, Lunar Takeoff and Return, fps	10,000
Re-entry Velocity, fps	36,000

References

[1] Hunter, M. W., and Tschingi, J. M., *The Advantages of High Thrust Space Vehicles*, ARS 991-59, November 1959.

[2] Ehricke, K. A., *A Systems Analysis of Fast Manned Flights to Venus and Mars*, ASME 60-Av-1, March 1959.

[3] Rom, F. E., and Johnson, P. G., *Nuclear Rockets for Interplanetary Propulsion*, SAE 63R, March 1959.

[4] Sutton, G. P., *Rocket Propulsion Systems for Interplanetary Flight*, Journal of the Aero/Space Sciences, Vol. 26, No. 10, pp. 609–625, October 1959.

[5] Edelbaum, T. N., *The Applicability of Small Nuclear Rockets to Space Missions*, Rep. M-1582-1, UAC Research Laboratories, November 1959.

[6] Konecci, E. B., Trapp, R. F., and Hunter, M. W., *Manned Nuclear Space Systems*, Aero/Space Engineering, Vol. 19, No. 2. pp. 34–41, February 1960.

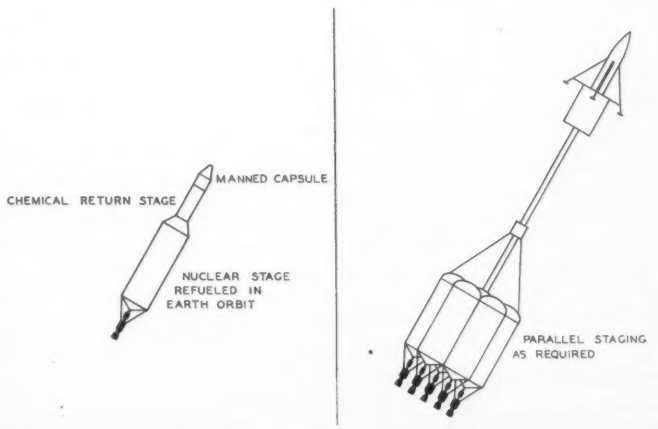

Fig. 7. Manned lunar vehicle (left). Cluster of Saturn nuclear third stages in earth orbit for deep space missions (right).

Nuclear Electric Power (Continued from page 19)

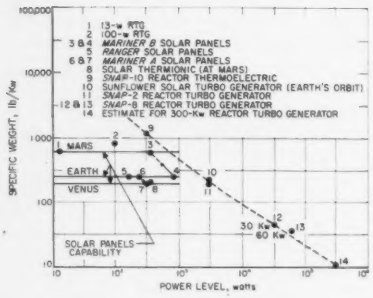

Fig. 2. Specific weights of power sources vs. power levels.

The advent of the *Saturn* booster—and the corresponding capability of placing spacecraft containing power systems of 500 lbs and more on trajectories to the moon, Mars and Venus—appears to be the earliest time at which the use of nuclear reactors as a source of secondary power becomes advantageous. As with the radiosiotope generator, the reactor systems appear particularly attractive for landing missions involving operation during the night portion of the cycle as a result of the absence of a requirement for energy storage. Missions to Mercury using advanced *Saturn* configurations also appear to be capable of making good use of a reactor for secondary power, although the weight margins are not great.

The most advanced chemically fueled *Saturn* configuration presently planned does not appear capable of delivering a sufficiently large spacecraft to Jupiter to permit use of reactor for secondary power. Solar power at Jupiter is not very attractive because of the relatively low solar flux level. Radioisotope sources appear feasible for this mission; however, owing to the low power level and large distances involved, the communication bandwidths would be very low. It appears that a more exotic propulsion system, such as a reactor-powered ion engine, will be required in order to deliver a vehicle with sufficient secondary power capability to provide adequate communication bandwidths. The primary power capability of such a system would be much greater than that required to satisfy the needs of the secondary power system.

Nuclear Electric Power for Space Propulsion

To establish a need for electric propulsion, it is ncessary to compare existing and planned systems. Such comparison is unfortunate because it implies competition. The objective of this presentation is not to establish a system competitive to chemical systems but to show that there are missions which can be satisfactorily accomplished only by electric propulsion. There are also other advantages that are not prime requirements, and these will be covered lightly.

Electric propulsion has many applications in spacecraft, such as attitude control, orbital control, mid-course maneuvers, terminal maneuvers, etc. Since the studies for these uses are still in progress, they will not be covered in this presentation. The electric propulsion covered includes only that propulsion necessary to take the spacecraft from an earth orbit and place it at its required destination. This destination may be a planetary fly-by, a planetary capture (arrive at the vicinity of the planet at the same time and with essentially the same velocity as the planet and therefore achieve some kind of planetary orbit), the planetary orbiter (whose altitude depends on the desired mission), or a combination orbiter and lander.

Since other factors are necessary to establish the *when* of development, no attempt will be made at this time to show a schedule of required development. Cost per pound of payload is a tremendous factor; until this can be analyzed and compared with possible development of other chemical systems, a proper electric propulsion development schedule cannot be established.

Chemically Propelled Spacecraft

The optimum trajectories for all spacecraft vary with each mission, each few pounds of payload, every change of specific impulse, etc. Therefore, the performance figures included in this portion can be challenged, and possibly errors can be shown to exist. Yet, these figures are probably within a factor of 2 or 3 and are definitely within an order of magnitude of what can be achieved by these systems. Three chemically propelled booster vehicle systems are considered. These are either developed or under development with enough assurance that they will be used for space exploration. In order to present their capabilities in as brief a manner as possible, Table 2 shows the amount of payload that they can place into a 100-nm earth orbit.

All three vehicles use liquid propellants and are staged. Vehicle II has four stages and a maximum of 29,000 lbs of fuel available in the orbital stage as part of the gross "payload" weight of 48,000 lbs. Such limitation on the available fuel indicates that, to obtain adequate mass ratios on some chemical missions, the weight placed in orbit must be less than 48,000 lbs. Extensive modification of computer trajectories may be necessary to eliminate these errors in payload weight calculation, for it would be obviously inefficient for a booster vehicle to put less than maximum weight into orbit. At present these modified computer studies have not been made, and resulting payload figures are probably on the low side.

Vehicle III is a five-stage vehicle. The fifth stage has not yet been specified, but the performance value used is an extrapolation of what could be achieved under the present development schedule.

Table 3 presents a portion of the studies and calculations made to date for the three vehicles. The figures shown are not necessarily for optimum performance since this depends on when the mission is to be flown and what the details of the mission are; they do bracket the capabilities of the three vehicles closely enough to establish at least an order-of-magnitude capability of payload weight.

There are several holes in this chart where data were unavailable at this writing. The zeros shown for vehicle I performing the Mercury and Jupiter

Table 1. Power and Weight Estimates for Space Missions

Date	System	Vehicle	Mission	Raw power	Power system weight
1961	Ranger 1 and 2	Atlas-Agena	Lunar	160	256
1962	Ranger 3, 4, and 5	Atlas-Agena	Lunar	160	144
1962	Mariner A	Atlas-Centaur	Venus	300	210
1963-64	Mariner B	Atlas-Centaur	Mars	350	300
1963-65	Surveyor	Atlas-Centaur	Lunar	---	---
1965-70	Voyager	Saturn	Mars, Venus Mercury, Jupiter	2500	500-1000
1966-71	Prospector	Saturn	Lunar	---	---

Table 2. Payload Capabilities

Vehicle	Gross payload, lb (for 100 n. mi. orbit)
I	13,000
II	48,000
III	50,000

fly-by missions are true data since this system does not have the capability.

There are two additional missions that this chart does not include. The first is a "shot out" of the plane of the ecliptic. Vehicle III is capable of placing approximately 12,000 lbs at 11-deg inclination angle and 2,500 lbs at approximately 22-deg inclination angle. This vehicle is also capable of placing a 2,500-lb payload to within a 0.24 astronomical unit from the sun with a flight time of roughly 40 days. There are many configurations of boosters and stages that can be shuffled around and may possibly give better performance than that shown here. There is no implication that the figures show the maximum the chemical systems can do. These are figures that apply to the existing planned vehicles, and obviously when plans for new systems are more complete their capabilities must be determined.

Electric Systems

The electric systems considered in this study consist of no specific accelerator or thrust device. The specific impulses were those which the extrapolated state of the art indicated could, with reasonable assurance, be achieved (in some cases by more than one type of accelerator). These accelerators cover the various forms of ion or electrostatic propulsion, the electrothermal systems, and possibly the magnetohydrodynamic devices, although, to repeat, the breakthrough for the production of flight equipment is not included in these estimates.

The electric power plants represented here do not include those being developed, planned, or even specified. They represent power levels and power-plant weights considered achievable at some future date. No scientific breakthrough is scheduled to accomplish these, although some engineering breakthroughs or inventions will undoubtedly be necessary before flight articles meeting these requirements are produced.

All of the spacecraft considered here use chemical systems to place them into an earth orbit. In other words, they are identical with the chemical systems, the difference being that the spacecraft includes a form of electric propulsion which is used to achieve Earth escape rather than relying on the chemical system. Table 4 is a brief description

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ASTRONAUTICAL ENGINEERS . . . to join a group currently making significant contributions to the national space effort. Studies include determination of economical methods for boosting payloads into orbit; maximizing payloads for inter-planetary missions; determination of satellite arrays for full-time weather observations of the earth's surface.
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Table 3. Payloads and Flight Times for Chemical Systems

Mission	Chemical system I		Chemical system II		Chemical system III	
	Time, days	Payload, lb	Time, days	Payload, lb	Time, days	Payload, lb
Venus Fly-by	87-133	1300	87-130	11200	-	-
	103-119	1600	103-119	12700	-	-
Venus Orbiter	-	-	87-130	1000	-	-
	-	-	103-119	1600-2300	-	-
Mars Fly-by	-	1650	-	-	-	11000
Mars Orbiter						
Elliptical	230	660	-	-	230	4700
Circular	260	320	-	-	230	3200
Mercury Fly-by	-	0	93	3500	96	3700
			97	4200	98	4100
Jupiter Fly-by	-	0	-	-	1000	6600
	-	-	-	-	500	3500
Saturn Fly-by	-	-	-	-	2190	4100
	-	-	-	-	1170	2500

of the boost vehicles considered. It shows the number of spacecraft pounds that can be placed into an approximate 300-nm orbit. There is no reason, other than an intuitive feeling, that 300 nm be established as the orbit. As the studies continue, undoubtedly a different orbit for the start-up of electric propulsion could be used. This may be selected for safety or other known performance reasons.

Boost vehicle II is a modified or more advanced version of the chemical vehicle I, shown in Table 2, and the boost vehicle I shown in Table 4.

Boost vehicle III of Table 4 corresponds to the chemical vehicle II shown in Table 2. There is deliberate attempt to use the smaller boost vehicles with the electrically propelled spacecraft to further emphasize the ability to put up larger payloads. This may also have an effect on the cost per pound of payload.

Four power plants were used in analyzing the capabilities of these systems. They do not necessarily represent specific power plants, yet the power outputs and weights are taken from development or anticipated future development as shown in Table 5. Note that lifetime is not considered in this comparison, even though when examining flight times it will be noted that we are talking of power-plant life expectancy of at least 10,000 hours (approaching 50,000 hours in the extreme missions).

Table 6 shows (within a factor of 2 or 3) the range of payload weights and flight times for the planetary missions. This table includes only power plant A and boost vehicles I and II. Table 7 shows a similar chart for power plant B and the three boost vehicles described. Table 8 shows power plant C and D with boost vehicle III.

There are many omissions in these tables where data are being generated. With limited manpower, and to minimize computer time, there is a tendency to obtain only those data that we feel are significant. By a little extrapolation, most of the other weights and flight times can be reached closely enough to establish whether there is a need for that specific mission.

Table 4. Payload Capabilities

Boost vehicle	Gross payload, lb (for 300 n. mi. orbit)
I	9,000
II	15,000
III	45,000

Table 5. Power-Plant Comparisons

Powerplant	Output	Pounds per kw
A	60	50
B	300	10
C	1,000	10
D	10,000	1

For an out-of-the-ecliptic shot, vehicle I and power plant A can achieve approximately 15-deg inclination. Vehicle I with power plant B can achieve approximately 40-deg inclination angle with an estimated 3,000-lb payload. A solar probe has not been thoroughly investigated since the initial power-plant design has sufficient temperature problems without adding the problem of getting closer to the sun. These data will be generated, though, sometime in the future.

Some studies have been made concerning use of electric propulsion for lunar missions. If time is not important, vehicle I can place 3,000 lbs into a 94-mile lunar orbit in approximately 100 days. If a slow "freight" is permitted, 5,000 lbs may be placed into a lunar orbit in about 300 days.

Scientific Missions

In evaluating the use of electrically propelled spacecraft, the space science implications were investigated. The purpose was to determine what problems—and what advantages—might exist using such a spacecraft. Four missions were considered—a Mars satellite, a solar probe, a Jupiter probe, and an out-of-the-ecliptic probe.

Using electrically propelled spacecraft for a Mars satellite as compared to a chemical system, it was determined that the slow spiral into the selected

Table 6. Payloads and Flight Times for Power Plant A

Mission	Boost vehicle I		Boost vehicle II	
	Time, days	Payload, lb	Time, days	Payload, lb
Venus Capture	240	1850	-	-
	380	4200	-	-
Venus Orbiter (500 n. mi. final orbit)	-	-	-	-
Mars Capture	300	1500	285	9000
	400	3200	390	12000
Mars Orbiter (500 n. mi. final orbit)	320	800	-	
	400	2250	-	-
Jupiter Fly-by	630	900*	-	-
	750	3100	-	-
Jupiter Capture	-	-	850	6000
	-	-	600	2500**
Mercury Capture	-	-	700	5000
	-	-	280	2500**

*Will escape solar system
**Electrothermal (arc jet) accelerator

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Table 7. Payloads and Flight Times for Power Plant B

Mission	Boost vehicle I		Boost vehicle II		Boost vehicle III	
	Time, days	Payload, lb	Time, days	Payload, lb	Time, days	Payload, lb
Venus capture	-	-	-	-	240	21000
	-	-	-	-	360	33000
Venus orbiter (500 n. mi. orbit)	-	-	-	-	-	-
Mars capture	-	-	-	-	-	-
Mars orbiter (500 n. mi. final orbit)	100	2600	180	4000	-	-
	320	5000	360	9500	-	-
Jupiter fly-by	-	-	400	7000	-	-
	-	-	600	10500	-	-
Jupiter capture	-	-	-	-	290	12500
Mercury capture	-	-	-	-	400	20500

Table 8. Payloads and Flight Times for Power Plants C and D, Boost Vehicle III

Mission	Power Plant C		Power Plant D	
	Time, days	Payload, lb	Time, days	Payload, lb
Venus capture	160	21000	-	-
	200	28000	-	-
Venus orbiter	-	-	-	-
Mars orbiter	180	4000	-	-
	400	28000	-	-
Jupiter fly-by	500	18000	-	-
	800	27500	-	-
Jupiter capture	500	14000	180	9000
	850	27000	400	25000
Mercury capture	160	10000	-	-
	260	24000	-	-
Saturn capture	730	12500	250	4000
	970	21000	550	26000

Table 9. System Comparison

System	Mars capture		Mars orbit		Jupiter probe		Mercury probe	
	Days	Pounds	Days	Pounds	Days	Pounds	Days	Pounds
Chemical I	230	660	260	320	-	0	-	0
Boost vehicle I								
Powerplant A	400	3200	400	2250	630	900	-	-
Boost vehicle II								
Powerplant A	390	12000	-	-	850	6000*	400	5000*
Powerplant B	-	-	360	9500	600	10500	-	-
Chemical III	230	4700	230	3200	1000	6600	88	4100
Boost Vehicle III								
Powerplant B	-	-	-	-	-	-	400	20500*
Powerplant C	-	-	400	28000	850	27000*	260	24000*

*Planet capture (elliptical orbit)

orbit provided an excellent opportunity to obtain complete and quite accurate values for any radiation belts, such as the Van Allen belt, which might exist at Mars. This slow spiraling should also enhance our ability to obtain the maximum information on the composition and structure of the Martian atmosphere.

There is no need to go into the details of the interest associated with a solar probe. Because of the temperature problem associated with such a probe, coupled with the anticipated problems of the power conversion systems in an electrically propelled spacecraft, it was decided that this should be postponed until a later date.

The Jupiter probe, with electric propulsion, is of particular interest, principally because of the timesaving involved. The electrically propelled spacecraft will actually reach Jupiter more quickly than the chemically propelled system and, with the 1-mw power plant, has a payload large enough to make many significant measurements. Since Jupiter is the closest of the major planets—that is, those planets which differ radically from the earth, Mars, Venus, and Mercury, both in composition and structure—it offers many exciting possibilities. Photographic investigation of the Jupiter satellites for comparison with our moon would produce some exceptional data. Radio astronomy has aroused much curiosity about the temperature and radiation belt trapped in Jupiter's magnetic field. Measurements of this magnetic field, etc., will be a great stride forward.

The out-of-the-ecliptic space probe is necessary to establish more data on such questions as, What is the rate of mass loss of the sun and other stars similar to it? If the probe can be placed far enough out of the ecliptic, even a photograph of our own solar system should produce important data.

The significant feature of this investigation is that it produced advantages for the use of electric propulsion systems for all but the solar probe. The advantages actually consisted of the time to spiral into planetary orbit, plus the available power for scientific instruments and communications after the destination was achieved. This implies that the power plant should have a lifetime in excess of that required for propulsion. Because of the flight time shown in the previous figures, the additional 60 to 100 days should not be a heavy restriction to place on these power plants.

Conclusions

It is unnecessary to dwell extensively on the nuclear power plant in the pro-

pulsion portion of this paper. When we speak of 50 lbs per kw or less, it appears that a nuclear source is the only one available at these power levels with the required lifetime expectation. The power conversion systems are subject to much discussion, and range from the turboelectric to direct conversion in the reactor. The low weight per kilowatt shown in the figures and tables will be achieved by furthering the state of the art in the conversion field.

Table 9 shows a gross comparison between those chemical systems included in this paper and the electrically propelled systems. Where it is unique, the electric system has been underlined in the table. There are other areas in the table where the electric system appears to give a significant advantage, but, as stated previously, other factors must be considered.

Certain engineering judgment will consider required lifetime for these missions unachievable for some years. Lifetime is certainly one of the big problems associated with the use of electric power in space. Yet, with straight chemical systems, a Jupiter or Saturn probe requires even longer life for the payload and its transmitter than does an electrically propelled spacecraft.

An additional advantage that electrical propulsion has is the opening up of the "firing window" that presently exists for some of our planetary probes. The payload curve is very steep in relation to firing time, and at present the window is measured in days. With electric propulsion it is conceivable that this firing window may be opened up to as much as 3 weeks. We expect that the effective exploration of space definitely requires nuclear electric propulsion. To obtain the scientific data we are seeking, we shall automatically use such systems. The research and the development necessary to bring about the application of this power to space vehicles must be encouraged.

Bibliography

General Trajectory Techniques

Irving, J. H., *Low Thrust Flight: Variable Exhaust Velocity in Gravitational Fields*, in Space Technology, Seifert, H. (Ed.).

Interplanetary Optimal Variable Thrust Programs

Melbourne, W. G., *Interplanetary Trajectories and Payload Capabilities of Advanced Propulsion Vehicles*, JPL TM 312-76, Jan. 5, 1961.

Lunar Orbiter Information

London, Howard S., *A Study of Earth-Satellite to Moon-Satellite Transfers Using Low-Chemical Propulsion Systems*, United Aircraft Report R-1383-1, May 21, 1959.

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Metals in Space (Continued from page 21)

tion. There is presently no evidence of such a phenomena nor is there any obvious way to estimate the probable rate for such a reaction.

However, it is interesting to calculate the maximum rates at which these metals could evaporate with no oxide film or with one so thin or so porous as to have little effect. The actual behavior of magnesium in this respect has been discussed at some length by Gulbransen and Andrew[13] who observed, as one might expect, that when the film is thick and coherent enough to retard oxidation it will also retard evaporation.

The evaporation rates at various temperatures were calculated and plotted as shown in Fig. 2. If the useful temperature limit is defined as that for which the evaporation is less than 0.1 mm per year the maximum useful temperatures are as follows:

Mg—198°C
Zn—147°C
Cd—95°C

The curves are based entirely on the Langmuir equation and the vapor pressure data compiled by Kubaschewski[14] and are almost straight lines.

Dissociation

A second means by which surface may be lost is dissociation of a protective oxide layer. Although there is no dependable way to calculate the actual rate of surface removal by this mechanism, the maximum rate of removal can be estimated by calculating the dissociation pressure of the oxide from its thermodynamic properties and then using this pressure in the Langmuir equation. Examples of this type of surface removal are the dissociation of copper oxide, silver oxide, molybdenum oxide, and iron oxide. Figs. 3 and 4 give the results of calculations of maximum rate of removal of oxide for these cases as a function of time and temperature. To obtain these curves, the dissociation pressures of Cu_2O, Ag_2O, MoO_2, and FeO as calculated from the data given by Kubaschewski[14] were substituted in the Langmuir equation and the thickness

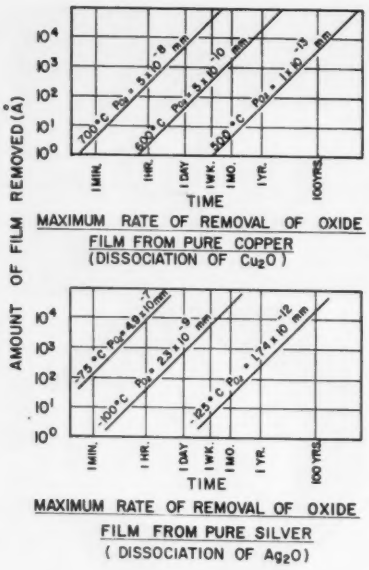

Fig. 3.

change calculated from the rate of loss of oxygen and the density of the oxide. A similar calculation for loss of a PbO film from Pb revealed that below the melting point of Pb this oxide is too stable to discompose even in ultra-high vacuum.

Diffusion

Surface films may also be lost from a metal by diffusion inward. This mechanism must be considered in cases where the solid metal has a high solubility for oxygen. Calculations on the loss of oxide films by diffusion are given in Fig. 5 for zirconium and titanium.

These curves were obtained from the usual solution of the diffusion equation for a semi-infinite bar initially free of oxygen with the face held at the solubility limit, C_s

$$C = C_s \, erfc \, (X/2\sqrt{Dt}) \text{ g cm}^{-3}$$

where X is a distance (cm), t is time (sec), C is the concentration (g cm^{-3}), C_s is the solubility (g cm^{-3}), D is the diffusion coefficient (cm^2 sec^{-1}), and *erfc* is the complementary error function. The flux of oxygen at the surface is

$$F(t) = -D(\partial C/\partial X)_{x=0} = C_s D(\pi Dt)^{-1/2} \text{ g cm}^{-2} \text{ sec}^{-1}$$

and the total flow to time t is

$$\int_0^t F(t)dt = 2C_s/\sqrt{\pi}\,(Dt)^{1/2} \text{ g cm}^{-2}$$

Replacing C_s (g cm^{-3}) by δS and dividing by (ρf) gives the following expression for the thickness change of the oxide

$$(\Delta E = 2/\sqrt{\pi}) \quad (\delta S/\rho f) \quad (Dt)^{1/2} \text{ cm}$$

Where δ is the density of the metal, ρ is the density of the oxide, S the weight fraction of oxygen in the saturated metal and f the weight fraction of oxygen in the oxide.

For thick films a solution is required which takes into account the motion of the phase boundary Such a solution was given by Jost,[15] used by Wagner *et al.*[16] for carbon in titanium and by Pemsler[9] for evaluation of D for oxygen in zirconium by observations of the change of film thickness. Pemsler's values given by $D = 9.4\ e^{(-51{,}780/RT)}$ were used in deriving the curves of Fig. 5 which agree within practical limits with his experimental film thickness measurements even though the motion of the phase boundary with respect to the metal is ignored.

Although no accurate data could be found for the diffusion coefficient of oxygen in titanium, the calculations were performed using $D_0 = 0.4$ (Dushman-Langmuir approximation) and $Q = 48{,}000$ (characteristic of the internal friction)[17] in the eq. $D = D_0\ e^{(-Q/RT)}$. The calculations assume a film of rutile of stoichiometric composition TiO_2, and alpha titanium containing 16.7 wt percent oxygen at the interface. The presence of nonstoichiometric rutile or lower oxides at the interface would probably not change the rate of film removal greatly, but a constant determined by the film thickness method used by Pemsler would be preferable for this purpose whether it represented the diffusion coefficient or not, so long as it was found to be independent of concentration.

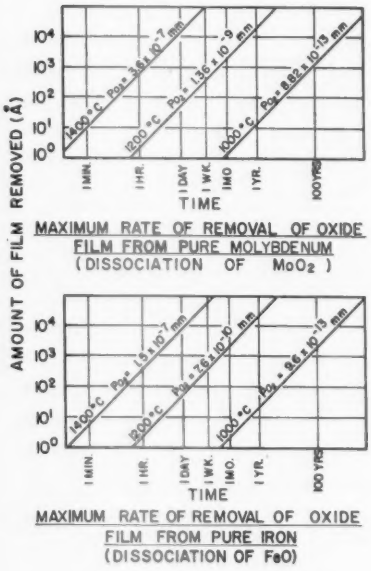

Fig. 4.

Diffusion Plus Reaction

Another means of surface film removal from metals will consist of a combination of diffusion and chemical reaction. The maximum rate of film removal may be estimated by combining diffusion calculations, equilibrium pressure of carbon monoxide, and the Langmuir equation. Rates for films sufficiently thick and continuous to impede CO removal will, of course, be lower than these maxima. Calculations of this type were made for three cases of increasing mathematical complexity. The first and simplest is represented by Fig. 6 showing the maximum initial rate of reduction of an MoO_2 film on molybdenum by Mo_2C which is generally present as an excess phase in arc cast molybdenum. Comparison with Fig. 4 illustrates the very important part played by carbon. This graph was obtained by substituting P_{co} (reference 14) for the reaction $2Mo_2C + MoO_2 = 5\ Mo + 2\ CO$ in the Langmuir equation. The actual rate would decrease with time from this maximum depending on the diffusion coefficient, solubility and activity of carbon in molybdenum. A more extensive discussion of this type of problem is given later in text.

The second case treated is that of reduction of an FeO film by carbon diffusing out of a gamma iron-carbon alloy. Since, according to the Langmuir equation the rate of CO evolution is proportional to P_{co} which in turn is proportional to the carbon concentration at the interface, and since the carbon is entirely in solid solution, this problem corresponds to that of heat loss at a rate proportional to surface temperature from the end of a semi-

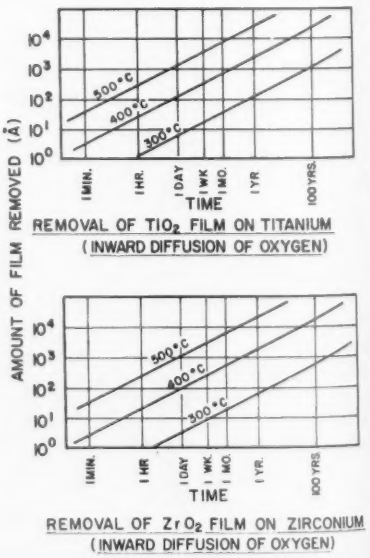

Fig. 5.

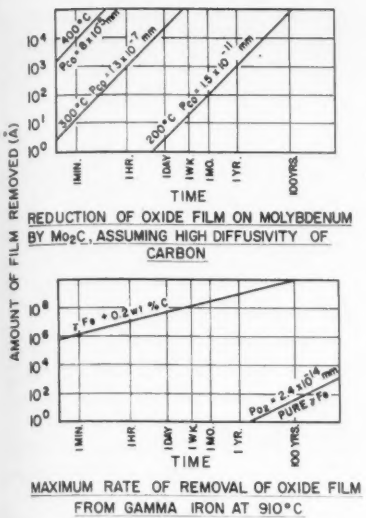
AMOUNT OF FILM REMOVED (Å)
TIME
1MIN.
1HR.
1DAY
1WK.
1MO.
1YR.
100YRS.
400°C
Pco = 8 x 10⁻⁵ mm
300°C Pco = 1.3 x 10⁻⁷ mm
200°C Pco = 1.5 x 10⁻¹¹ mm
REDUCTION OF OXIDE FILM ON MOLYBDENUM BY Mo2C, ASSUMING HIGH DIFFUSIVITY OF CARBON
γ Fe + 0.2 wt % C
Po2 = 2.4 x 10⁻¹⁴ mm
PURE γ Fe
MAXIMUM RATE OF REMOVAL OF OXIDE FILM FROM GAMMA IRON AT 910°C

Fig. 6.

infinite bar initially at uniform temperature. Carslaw and Jaeger[18] (p. 53) give the following expression for surface temperature (or concentration g cm^{-3}) for this case:

$$C_s = C_0 e^{b^2 Dt} \operatorname{erfc} (b\sqrt{Dt})$$

where C_0 is the initial concentration in g cm^{-3}, D is the diffusion coefficient in cm^2 sec^{-1}, t is the time in sec and b is defined as h/D, where h is the proportionality constant between the flux of carbon through the surface and the surface concentration.

By our definition of b, the flux of carbon at the surface is $F_c = -DbC_s$ so that the change in film thickness (ΔE) up to any time t is

$$\Delta E = -gDbC_0 \int_0^t e^{b^2 Dt} \, erfc \, (b\sqrt{Dt}) \, dt$$

where g is the g of FeO reduced per g of carbon, divided by the density of FeO.

Expressing erfc $(b\sqrt{Dt})$ as an infinite series[19] permits reduction of this expression to

$$E = (-2g \, Co/\sqrt{\pi}) \sqrt{Dt} \, [1 + (1/2X^2) - (1/4X^4) + (1{\cdot}3/8X^6) - (1{\cdot}3{\cdot}5/16X^8)]$$

where $X = b\sqrt{Dt} = h\sqrt{t/D}$.

The value of h is found by substituting p_{co} for the reaction C + FeO = Fe + CO into the Langmuir equation and depends on the activity coefficient of carbon in gamma iron. Based on the thermodynamic data of Kubaschewski[14] and the activity values of R. P. Smith,[20] h is so large compared to the values of t/D of interest (0.2 wt percent carbon) in this particular case that the infinite series reduces to 1 and the eq. reduces to that characteristic of a semi-infinite bar with face held at zero concentration.

$$E = (2g \, Co/\sqrt{\pi}) \sqrt{Dt}$$

Using this equation and the diffusion coefficients given by $D = .01e^{(-33{,}000/RT)}$ (reference 21) for carbon in gamma iron at the lowest temperature where it applies (910°C) the curve of Fig. 6 was derived. For comparison the change in the FeO film thickness due to simple decomposition of FeO from carbon-free iron is also shown.

The third and most complex case of this type considered was that of the reduction of a film of FeO on the surface of alpha iron containing 0.2 percent carbon. The results are shown in Fig. 7. The effectiveness of carbon is demonstrated by comparison with Fig. 4. This case involves not only the radiation boundary condition expressing the proportionality of the rate of CO evolution to the concentration (activity) of carbon at the oxide-metal interface, but also recognition of the increasing thickness of the carbide-free layer between the oxide and the 0.2 percent carbon alloy containing excess carbide. Thus, formally, a dimensionless variable $\gamma = (E/2\sqrt{Dt})$ such as used by Jost[15] should be introduced (where E represents the thickness of the carbide-free ferrite layer). A simple formal solution for these conditions would be exact for thick films but has not yet been worked out. Therefore, since the diffusion coefficient of carbon in ferrite is rather high and the solubility low, the change of film thickness with time was calculated by assuming the concentration gradient to be independent of X, equating the momentary carbon flux to the rate of carbon loss as CO according to the Langmuir equation and integrating over arbitrarily selected successive time intervals, using carbide-free ferrite layer thicknesses consistent with the amount of carbide present in an 0.2 percent carbon steel. The solubility, activity, and diffusion coefficient values used were those of Smith[20] and Stanley.[22]

The reduction of the MoO_2 film on arc cast molybdenum by Mo_2C (discussed above) is another example of the numerous cases of this type which arise. A formal mathematical treatment for these cases would be very welcome, but accurate values of the solubility, activity coefficient and diffusion coefficient are also required and these are available in only a few instances. Accurate experimental data on oxide film thickness changes in ultrahigh vacuum combined with proper mathematical analysis should help in compiling fundamental data of this type.

Classification

Table 1 classifies various metals according to the means by which surface

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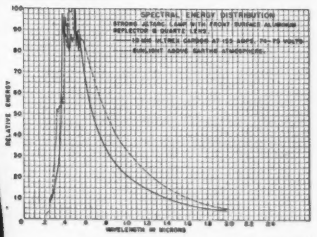

A continuous spectrum is available from .25 to 5.+ microns, with the spectral energy distribution very close to solar energy distribution above the earth's atmosphere.

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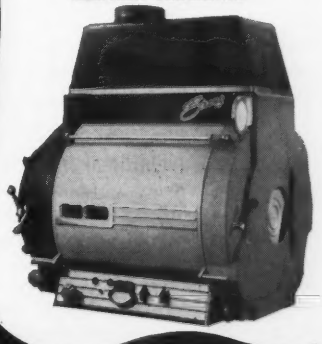


Table 1. Metal Evaporation and Removal of Oxide Films From Metals [Approximately the Minimum Temperatures (°C) for Removal of 100 Angstroms of Either Metal or Oxide in a Year]

Material	Metal Evaporation*	Oxide Evaporation	Oxide Diffusion	Oxide Dissociation	Carbon Reduction
Mg	100	n	n	n	n
Al	p	n	n	n	n
Zn	60	n	n	n	n
Cd	20	n	n	n	n
Pb	p	n	n	n	n
Cu	580	n	n	510	n
Ag	n	n	n	−127	n
Cr	580	p	n	n	p
Fe	730	n	n	1040	<100
Co	815	p	n	850	p
Ni	770	840	n	800	p
Ti	n	n	300	n	n
Zr	n	n	310	n	n
Mo	n	n	n	1050	180
W	n	n	n	1100	p

* From oxide-free surface or through porous oxide.
n—negligible compared to alternate mechanism of oxide removal.
p—probably an important factor.

layers may be removed on long exposure in space, and gives approximate temperature for removal of 100 angstroms in a year of either metal or oxide based on the calculated maximum rates. Estimated temperatures are also given for aluminum, lead, nickel, cobalt, chromium, and tungsten.

Conclusions

Rate of oxidation. At the residual gas pressures encountered in space a metal surface once clean will remain so for years. At the pressures usually obtained in laboratory vacuum work (10^{-4} to 10^{-6} mm) a clean surface will be contaminated in seconds. At the best pressures now attainable in the laboratory (10^{-10} mm) a minimum of several hours will be required to form a monolayer on a clean surface.

Mechanical removal of oxide from metals. The formation of oxide free metal surfaces may occur in space or in laboratory ultrahigh vacuum test facilities by abrasion of a metal surface or by crack formation during failure of a metal.

Chemical removal of oxide from metals. At elevated temperatures and during long exposure in space oxide surfaces may be removed from some metals by chemical and chemical-physical means. These mechanisms include (a) evaporation of metal or metal oxide, (b) dissociation of oxides, (c) diffusion of oxygen, or (d) diffusion of carbon to reduce surface oxides.

Theoretical calculations indicate that in ultrahigh vacuum the temperatures required for cadmium, zinc and magnesium to evaporate at 0.1 mm per year are 95°C, 147°C, and 198°C, respectively. Oxide films on these metals may be dislodged by such evaporation. Further calculations indicate that oxide films up to 100 angstroms thick would completely dissociate in a year or less from Ag, Cu, Fe, and Mo at approximately −127, 510, 1,040 and 1,050°C, respectively. Temperatures for diffusion inward of 100Å thick layer of oxide in a year on Ti or Zr are about 300°C. Temperatures for carbon reduction of 100Å thick oxide layer on Fe and Mo containing carbon may be below 200°C.

For the metals Al, Pb, and Cr below their melting points, oxide films would not be removed by dissociation even in a year, but oxide would be removed from solid Cr by both oxide and metal evaporation and possibly from Al and Pb by metal evaporation. Oxide evaporation may also contribute to oxide removal from Ni and Co. As in the case of Fe and Mo, oxide films on Co, Ni, and W may be removed at rather low temperatures when carbon is present.

Effect on properties. Experimental work at moderate vacuum shows that coefficient of friction, fatigue properties, and creep-rupture properties of metals are affected by reduced pressures and these effects have been related to changes in rate of oxidation and to surface condition of the metals tested. Since both rate of oxidation and surface cleanliness will be very much affected by reducing pressure to 10^{-10} mm Hg or less, it is anticipated that even more marked effects on mechanical properties will be observed in this pressure range. For this reason the behavior of metals should be studied under ultrahigh vacuum conditions.

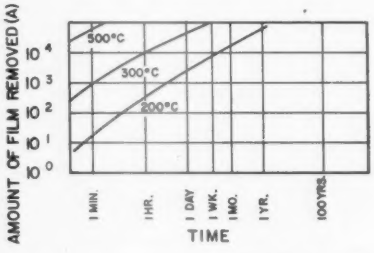


Fig. 7. Maximum rate of removal of oxide film from alpha iron containing 0.2 wt percent of carbon ($FeO + C \rightarrow Fe + CO$).

References

[1] Bowden, F. P., and Tabor, D., *The Friction and Lubrication of Solids*, pp. 145–159, Oxford University Press, London, 1950.

[2] Bowden, F. P., and Young, J. E., *Friction of Clean Metals and the Influence of Adsorbed Films*, Proc. of the Royal Society, Series A, Vol. 208, p. 311, London, 1951.

[3] Bowden, F. P., and Young, J. E., *Friction of Diamond, Graphite and Carbon and the Influence of Surface Films*, Proc. of the Royal Society, Series A, Vol. 208, p. 444, London, 1951.

[4] Epifanov, G. I., *Friction as Resistance to Shear of Thin Surface Layers on Solids*, Doklady Akademi Nauk, Vol. 114, No. 4, pp. 764–767 (Brutcher Translation No. 4327), U.S.S.R., 1957.

[5] Levitskii, M. P., *Formation and Breakdown of Welding Bridges between Friction Surfaces*, Doklady Akademi Nauk, Vol. 92, No. 4, pp. 797–798 (Brutcher Translation No. 3403), U.S.S.R., 1953.

[6] Shahinian, P., and Achter, M. R., *A Comparison of the Creep-Rupture Properties of Nickel in Air and in Vacuum*, Trans. AIME, Vol. 215, No. 1, p. 37, 1959.

[7] Wadsworth, N. J., and Hutchings, J., *The Effect of Atmospheric Corrosion on Metal Fatigue*, Phil. Mag., Vol. 3, p. 1154, 1958.

[8] Dushman, S., *Scientific Foundations of Vacuum Technique*, John Wiley & Sons, Inc., New York, 1949.

[9] Pemsler, J. Paul, *Diffusion of Oxygen in Zirconium and Its Relation to Oxidation and Corrosion*, Jnl. Electrochem. Soc., Vol. 105, 1958.

[10] Hirth, J. P., and Pound, G. M., *Evaporation of Silver Crystals*, Trans. AIME, Vol. 215, p. 932, 1959.

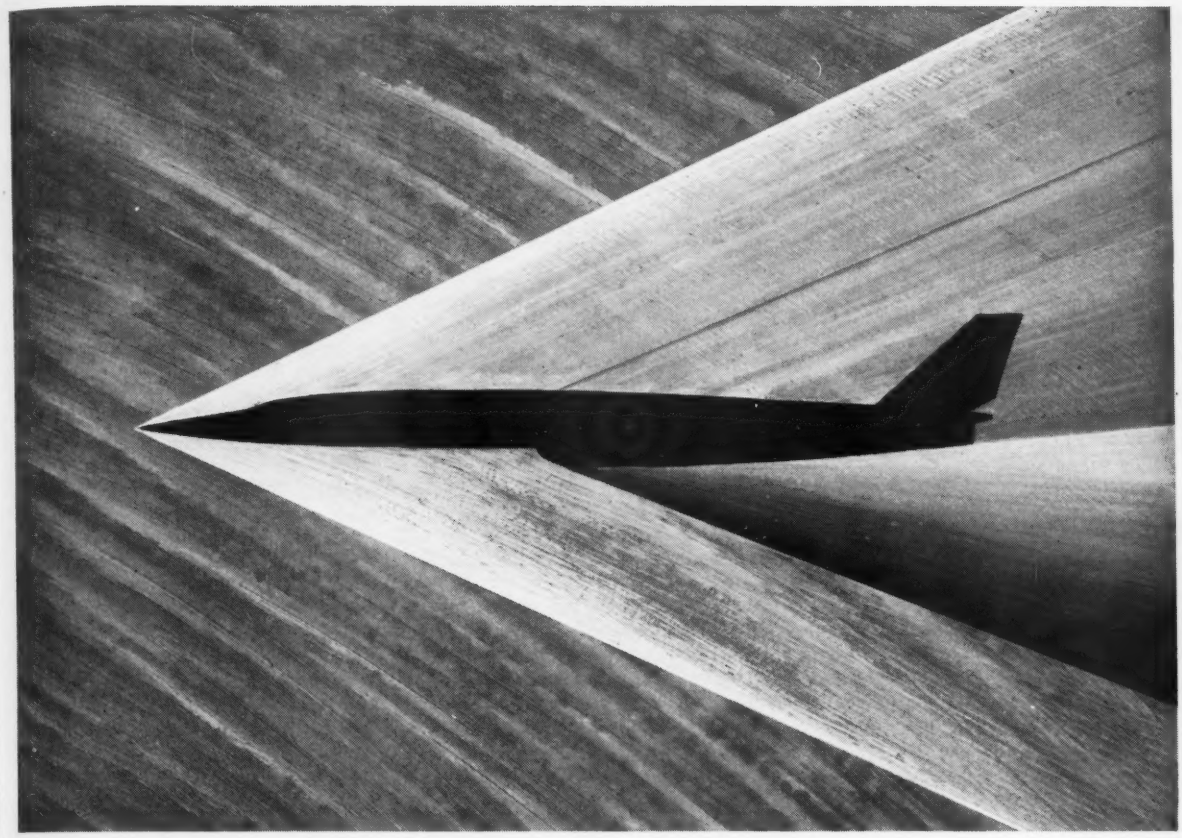
[11] Becker, J. A., *Study of Surfaces by Using New Tools*, Solid State Physics, Vol. 7, p. 379, Academic Press Inc., New York, 1958.

[12] Gulbransen, E. A., and Andrew, K. F., *Kinetics of the Reaction of Zirconium with O_2, N_2 and H_2*, Trans. AIME, Vol. 185, p. 517, 1949.

[13] Gulbransen, E. A., and Andrew, K. F., *Reactions of Metals in High Vacua*, J. Phys. and Colloid Chem., Vol. 53, pp. 690–711, 1949.

[14] Kubaschewski, O., and Evans, E. L. L., *Metallurgical Thermochemistry*, Pergamon Press, New York, 1958.

[15] Jost, W., *Diffusion in Solids, Liquids*



Mach 3 Technology

Designing a plane to ride triple-sonic shock waves like a surfboard

For years manned aircraft have been imprisoned in their own V-shaped shock waves which were created when traveling at high speeds. These waves caused a tremendous increase in drag, and a consequent heavy penalty had to be paid in fuel consumption, limiting the range of supersonic flight.

This was the problem facing the engineers at the Los Angeles Division of North American Aviation as they designed the Mach 3 B-70 Valkyrie airplane for the Air Force. The answer lay in an entirely new principle of aerodynamic science which had been discovered by the former National Advisory Committee for Aeronautics. This principle was that, properly designed, a triple-sonic aircraft could actually ride its own air patterns somewhat like a surf-rider on the crest of a wave.

North American engineers set out to design a wing and undersurface which would make use of this aerodynamic principle. The result was a delta wing shaped in the V which would be made by air waves when flying at Mach 3 speeds. The design was highly practical. With this new design advance, there now exists a means for manned aircraft to not only reach triple-sonic dash speeds, but to cruise for intercontinental distances at them.

Advanced design achievements like this will help sustain America's leadership in aircraft by making possible the Mach 3 B-70 and future commercial aircraft.

Builders of the B-70 Valkyrie

THE LOS ANGELES DIVISION OF NORTH AMERICAN AVIATION, INC.

and Gases, pp. 68–72 Academic Press Inc., New York, 1952.

[16] Wagner, F. C., Bucur, E. J., and Steinberg, M. A., *The Rate of Diffusion of Carbon in Alpha and Beta Titanium*, Trans. ASM, Vol. 48, p. 742, 1956.

[17] Pratt, J. N., Bratina, W. J., and Chalmers, B., *Internal Friction in Titanium and Titanium-Oxygen Alloys*, Acta. Met., Vol. 2, No. 2, p. 207, 1954.

[18] Carslaw, H. S., and Jaeger, J. C., *Conduction of Heat in Solids*, Oxford Press, London, 1947.

[19] Pierce, B. O., *A Short Table of Integrals* (Third revised Ed.), p. 120, Ginn & Co., Boston, 1929.

[20] Smith, R. P., *Equilibrium of Iron-Carbon Alloys with Mixtures of CO-CO_2 and CH_4-H_2*, Jnl. Am. Chem. Soc., Vol. 68, p. 1172, 1946.

[21] Wells, C., and Mehl, R. F., *Rate of Diffusion of Carbon in Austenite in Plain Carbon, in Nickel and in Manganese Steels*, Trans. AIME, Vol. 140, pp. 279–306, 1940.

[22] Stanley, J. K., *The Diffusion and Solubility of Carbon in Alpha Iron*, Trans. AIME, Vol. 68, p. 760, 1949.

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Tubular Truss Core Sandwich *(Continued from page 23)*

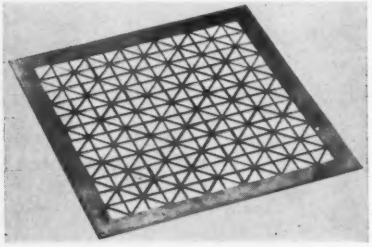

Fig. 3. Perforated stainless steel skin.

simple. So is panel skin splicing by means of butt welding.

One should also look at possible disadvantages of the proposed structure as follows:

1. Not all the skin material is working when loaded in axial compression. This undesirable feature can be overcome in some applications by orientating the ribs appropriately.

2. The chem-milled skin carries extra weight in the fillets of the ribs. Also, rib width tolerances are difficult to hold. A combination of rolling ribs into a sheet and finish chem-milling appears to be very promising.

3. Spot welding is difficult to inspect and is not recommended for tension applications. However, the techniques in this field are improving rapidly. Special machines are being made available for special spot welding jobs.

4. The core-skin assembly cannot be made in one piece such as can be done by gluing or brazing. However, by the same token the very close tolerances required for the latter operations are not required here.

5. The tubes may behave as eccentric columns. Careful joint design may overcome this problem.

6. Different core and face materials are not practical. This situation may be overcome in special cases.

7. Sealing may be a problem. However, methods exist for circumventing this predicament.

8. Fatigue, vibration, and flutter behavior may be unsatisfactory. Various tests are required to check these items. Preliminary testing looks very encouraging.

9. Local attachment bosses cannot be added when required after the design is frozen. However, attaching plates can be used which can be tied into neighboring bosses.

Often, one does not need a closed sandwich—i.e., one with solid faces. In fact, if the structure is used as the wall of a fuel tank, having one face open may be advantageous. In this way, thermal stresses are kept low and practically the complete volume is available for fuel. Also, internal baffles are possible.

If desired, closing of an open sandwich can be accomplished in various ways. If sealing is not a problem, ordinary lightweight porous materials are available. In fact, in some applications ablative coverings may be used. Several nonporous plastics are available when sealing is required. Thin metal sheet could also be used.

The big advantage of an open sandwich is ease of fabrication, inspection, and repair and/or modification of the core. Also, effective skin gage—i.e., equivalent weight gage—can be made light when loads are light or the working stress is relatively low. For example, a skin initially of gage 0.02 can be reduced to a skin of equivalent weight of 0.002 by proper perforation—i.e., 90 percent of the material can be removed.

The great advantage of using a chem-milled face is the ability to leave material where it is needed. For example, one may leave a boss where a concentrated load is to be introduced. Such a design is shown in Fig. 5. Edge members are left along the edges of a panel for purposes of introducing loads and joining (Fig. 6). Splicing of a tubular core is simple. Denser core may be added by using larger size tubing or heavier wall tubing or both. In some cases, it may be desirable to start with heavier wall tubing and chemically mill

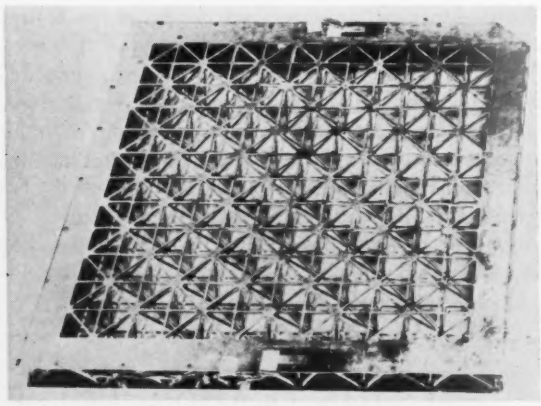

Fig. 4a. Assembled sandwich, front view, 14 × 14 × 1 in.

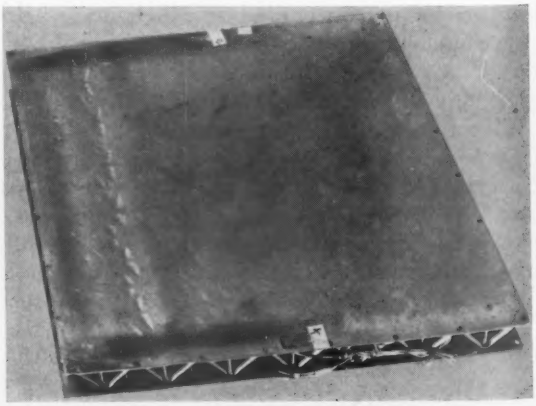

Fig. 4b. Assembled sandwich, back view.

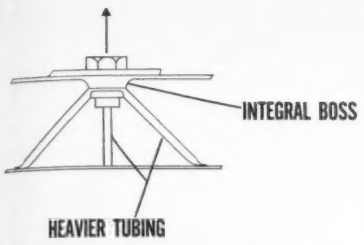

Fig. 5. Localized beef-up for taking concentrated load.

between support points. Such tubes would make for sturdier connecting areas.

Strength and Weight Properties

1. Core

The weight of the steel tubing shown in Fig. 1 is about

$$2(4 \times 1.41/4) \times 0.00113 \times 1 \times 0.286 \times 1{,}728 = 1.57 \text{ lb/ft}^3$$

where

$$0.00113 = \pi Dt = \pi .06\ (0.006)$$

The shear stiffness of this core is at least

$$G_c = (1/2)\ \frac{29 \times 10^6(0.00113)}{2(0.707)^2 1.41} = 12{,}000 \text{ psi}$$

It is interesting to note that an hexcell core of 0.002 wall and 3/8 cell weighs about 3.4 lb/ft³ in aluminum and has a transverse G value of about 16,000 psi. Furthermore, the weight of *each* glue line that is used in a glued sandwich is about equal in weight to this aluminum core when the core is one inch in depth.

The L/ρ of each member of the tubular core is about 66. Consequently, one could expect a working stress of about 65,000 in compression. On the other hand, the working stress of the aluminum core is only

$$5.35E(t/b)^2 = 5.35 \times 10.5 \times 10^6 \times (0.002/0.375)^2 = 1{,}500 \text{ psi.}$$

2. Chem-Milled Skin Weight

It is convenient to use the idea of equivalent weight skin in talking about such skins as shown in Fig. 2. Let t_0 be the actual thickness of the initial skin before chem-milling. Then the equivalent weight thickness after chem-milling a pattern such as shown in Fig. 2 is:

$$t_w = t_f + \frac{(2 + 1.41)\ [w(t_0 - t_f) + 0.43(t_0 - t_f)^2]}{a}$$

where

t_f = final sheet thickness
w = width of ribbing
a = small side of triangle

Thus, if $t_0 = 0.06$, $t_f = 0.006$, $a = 1$, and $w = 0.04$,

$$t_w = 0.006 + (3.41)\ [0.04(0.054) + 0.43(0.054)^2] = 0.006 + 0.0116 = 0.0176$$

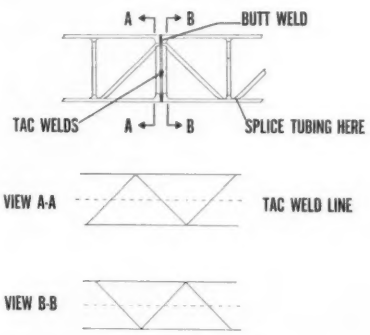

Fig. 6. A technique for joining two panels.

This equivalent weight thickness is the one of the sheet shown in Fig. 2. However, if t_0 is taken to be 0.04, we obtain $t_w = 0.006 + 0.00681 = 0.0128$.

3. Perforated Sheet Weight

The equivalent weight thickness here is nearly that given in 2 above minus t_0. Thus, the sheet shown in Fig. 3 has been reduced to an equivalent weight thickness of about 0.0116. If t_0 is reduced to 0.04, we obtain $t_w = 0.0068$. Therefore, a structure in which two such perforated sheets are used (and the core in Fig. 1) would have a total equivalent weight thickness of about 0.016. Lighter weights are possible by using lower values of t_0. For example, if $t_0 = 0.02$, the equivalent weight is about 0.002, 2 mils, for one perforated skin.

Strength of Sandwich

The loading condition of primary interest is edgewise compression. If the core is stiff enough, one should be able to work the skin material close to its compressive yield strength. A crude criterion for measuring how much core shear stiffness is necessary is given by the following relation:

$$N_{act} = \frac{1}{(1/N_{des}) + (1/G_c)}$$

Here N is edge compressive loading in lb/in. and G_c is the shear modulus for the core. The subscripts "act" and "des" refer to actual and desired. Therefore, if we desire an allowable N of 1,000 lb/in., in the present case we obtain about

$$N_{act} = \frac{1}{(1/1{,}000) + (1/12{,}000)} = 925 \text{ lb/in.}$$

Thus, we see that the core is sufficiently strong for such requirements.

Now one must investigate the strength of the skins for local buckling between supports. An easy criterion for this strength is simply the column strength of the ribbing. The L/ρ of a typical short rib can be made reasonably small by proper design. For example, the L/ρ for the short ribs in Fig. 3 is about 50. Therefore, one should be able to work this steel material to a compressive stress of about 100,000 psi. The diagonal ribs are longer but are less severely loaded than the short ribs. Notice that the horizontal ribbing serves a useful function even though it does not accept compressive loading. Actually, this ribbing acts in tension and serves as supporting structure for the short ribbing.

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Launching & Recovery Systems (Continued from page 25)

grammatically depicted in Fig. 6. A long metal tape is coiled and placed within a "reel housing." Tape pays out from the center of the coil, elevates to pass over the remaining coils and enters the "roller housing." Within the "roller housing" a series of rollers subjects the tape to plastic bending to absorb the engaging energy (Fig. 7) in the form of strain energy and, therefore, precludes the use of the tape for a second engagement. The number of rollers installed determines the energy absorption capacity. Re-battery time is on the order of 30 min, under optimum conditions. A multiple installation which would not be too expensive is required if consecutive-engagement capability is desired. Tests are now underway for the U.S. Air Force on a full-scale prototype designated as BAK-7/F32A with a nominal energy-absorption capacity of 44 million ft lb. By placing one additional unit on each side of the runway, the energy capacity could be doubled. Successful engage-

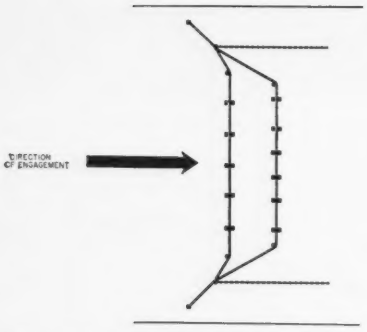

Fig. 3. The E-5-1 emergency chain arresting gear. Note preformed pendant.

formance spectrum and component service life.

The Navy's newest emergency arresting gear TM-21 is now being designed and constructed by the Hydromill Company, located in Santa Monica, Calif. It is scheduled for initial tests at NATF(SI) in late spring of 1961 (Fig. 10). This system also employs a nylon tape and reel concept similar to the TE-15 arresting gear; however, the reel shaft is coupled to a liquid turbine which will pump and heat water above the boiling point utilizing the latent heat of evaporation of water for dissipation of energy. Fig. 11 illustrates a comparison of the E-5-1, BAK-7, TE-15, E-14-1, and TM-21 Prototype.

For many years the Navy was the sole participant in the development of aircraft arresting gear for land installations. Over the last several years, the Air Force has been taking an increasingly more active part. The Davis Barrier adaptor, mentioned earlier in this article, when connected to anchor chain is their standard MA-1A barrier. Not only are Air Force fighter bases also being equipped with chain gear, water squeezer or Bliss rotary friction brake tail hook engaging equipment, but large-span remote-controlled self-erecting nylon barricades are being installed in some locations. McClellan Air Force Base has a 200-ft wide, 24-ft high arrangement patterned after the NAESI 120-ft span shipboard design. Travis Air Force Base is working on a 300-ft wide barricade capability. These barricades are attached to conventional anchor-chain momentum or friction absorbers. A somewhat different Swedish design, called the BEFAB nylon barricade, is to be tested at NATF(SI) for possible Marine Corps and NATO application. A pop-up or wire-rope throwing development is also underway at Edwards Air Force Base for B-58 engagements, the cross-runway pendant in this case being programed to catch the main landing gears after passage of the nose wheel. Early this spring, a TE-15 installation will be made at Edwards Air Force Base. After it has been evaluated by the Navy, with its largest carrier aircraft, the A3D, the installation will be used to arrest the B-47. The possibility of a hard-bottomed pond with a programed bottom profile for arresting B-52 and KC-135 aircraft was studied by Wright Air Development Division personnel. WADD TN 60-167 covers their comprehensive analysis and con-

Fig. 4. The F3H aircraft seen just engaging No. 1 cross-deck pendant of the E-5-1 arresting gear.

ments have been made with a 25,000-lb deadload at speeds up to 202 knots.

Highest energy-absorption capacity has been demonstrated by the Navy's TE-15 dual-tandem rotary friction-brake arresting gear developed by the E. W. Bliss Company (Figs. 8 and 9). A unique feature of this arresting gear is the use of nylon purchase tapes in lieu of wire rope. In practice, four nylon tapes are each stored on separate reels. The tapes in pairs are coupled to the wire-rope deck pendant. Upon aircraft engagement, the tape reels are set in motion. Concurrently through a sprocket drive, a hydraulic pump applies programed hydraulic pressure to B-52 aircraft wheel brakes mounted on the reel shafts. The aircraft engaging energy is dissipated in these brakes. Development tests with deadloads have been successfully completed by the contractor. The upper speed limit in the lower weight range has been demonstrated at 180 knots and 70,000-lb deadloads have been engaged at 147 knots, representing an energy level of 69 million ft lb. Retractions can be accomplished with a 15-hp electric motor in 4 to 5 min. NATF(SI) is subjecting the TE-15 to additional testing to better establish the per-

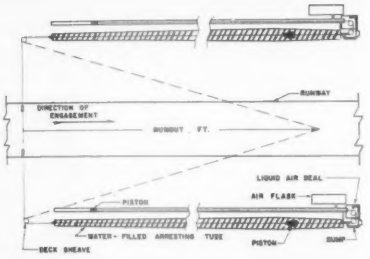

Fig. 5. Diagram of simplified water-squeezer type arresting gear.

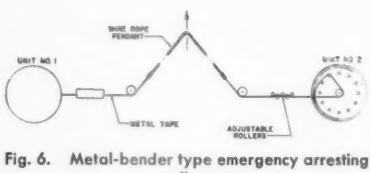

Fig. 6. Metal-bender type emergency arresting gear diagram.

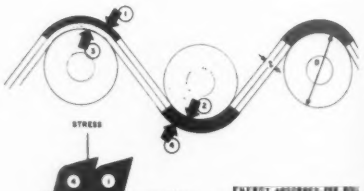

Fig. 7. Energy absorption factors of the metal-bender type emergency arresting gear.

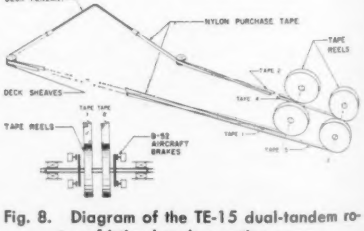

Fig. 8. Diagram of the TE-15 dual-tandem rotary friction-break arresting gear.

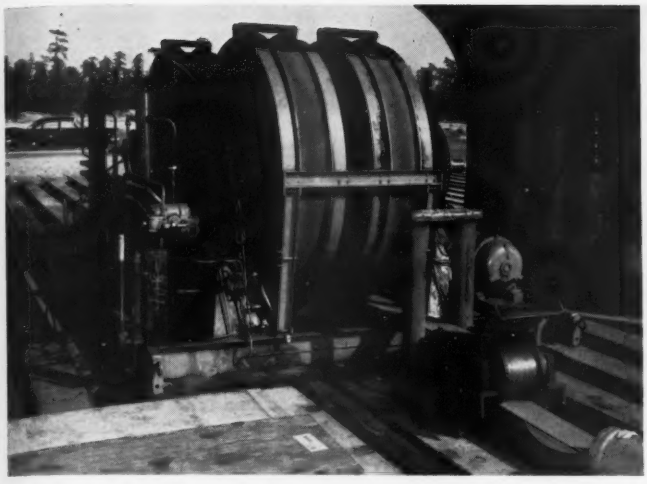

Fig. 9. View of the TE-15 arresting gear in action. Note nylon purchase tape winding into tape reels.

senger comfort might place the maximum g load at a lower value, thereby increasing the aircraft runout. Fig. 12 shows a tail-hook equipped C-131 Convair commercial aircraft engaging an arresting gear at All American Engineering Company field, Georgetown, Del. This demonstration was sponsored by the FAA last June and is considered an aviation "first." A KC-135 is now to be equipped with a tail-hook by All American and will be tested here, or at Edwards Air Force Base, in a few months.

Hook or pop-up arrangements with various-type arresting gears are currently being proposed for commercial passenger and cargo planes which take the energy level up to 200 million ft lb. Payload and safety can thereby be increased with existing runway lengths. This is especially important where

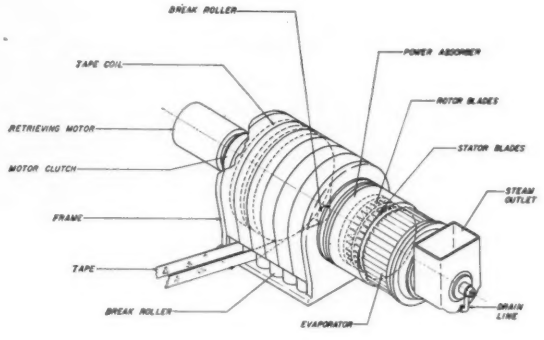

Fig. 10. TM-21 emergency arresting gear diagram.

cludes that further effort on this concept is not warranted.

Recently the Federal Aviation Agency (FAA) has become interested in the utilization of arresting gear for installation at commercial airfields. The FAA is currently thinking along the lines of utilizing an arresting gear to assist the aircraft which is already employing brakes and reverse pitch or thrust. Stopping distances are envisioned to be within 1,000 to 1,500 ft at engaging speeds of 120 to 130 knots. With this operational concept in mind, initial goals for arresting-gear energy-absorption capacity are placed in the 100 million to 150 million ft lb regime. The most stringent requirement is the desire to limit the total maximum aircraft horizontal deceleration to a value of one g. Consideration of pas-

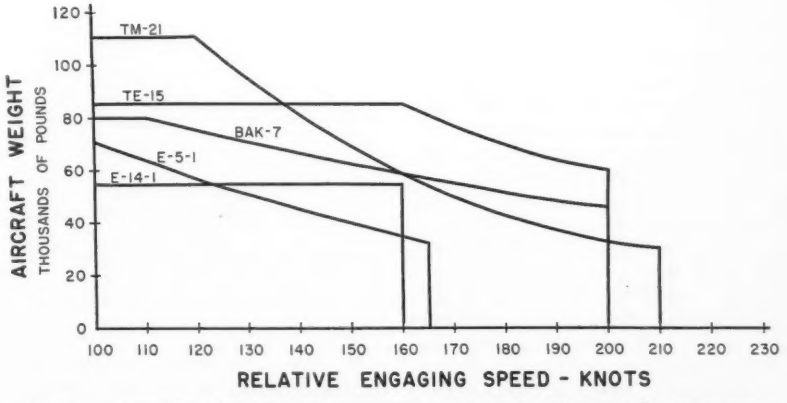

Fig. 11. Comparison of runway emergency overrun arresting gear performance (according to manufacturer's design targets). E-5-1 is for emergency chain ARG with shaped pendant [NAEF(SI)]. TM-21 is for hydro-brake arrester model HM3 (Hydromill Co.). BAK-7 is for Air Force metal bender twinned units (Van Zelm Associates). E-14-1 is for water squeezer (All American Engineering Co.). TE-15 is for rotary friction brake (E. W. Bliss Co.).

Fig. 12. Tail-hook equipped C-131 Convair commercial airliner seen just engaging arresting gear.

additional real estate for runway extensions is difficult to obtain. At present, the FAA is studying arresting possibilities for the new Dulles International Airport. Perhaps this will be the forerunner of arrested landings for commercial jet airliners. They might even find earlier justification at airports such as LaGuardia, Pittsburgh, Charleston, San Francisco, etc., where certain runways may be critical from dikes, drop-off, or waters'-edge termination conditions.

Manned with specialized personnel and equipped with a variety of modern gear and versatile testing sites, the U.S. Naval Air Test Facility (Ship Installations), Lakehurst, N.J., is uniquely capable of meeting the challenge of testing and evaluating currently planned arresting devices and those of the future.

+ + +

Aerospace Nuclear Safety (Continued from page 27)

the food chain, by direct inhalation, and by ingestion of the suspended particles. Operational personnel could also be subject to neutron and gamma radiations during test, installation, and launch procedures. However, adherence to standard radiation safety procedures can control this.

4. *Operational Considerations and Objectives*

A slight possibility exists that, if an accidental release of fission products (for systems operated from the continental United States) were to occur, small segments of the population of the United States might possibly be subjected to radiation doses above the presently accepted limits for the entire population at large (170 millirem (mr) per capita per yr.). The Federal Radiation Council Guides (FRC) suggest 500 mr per yr. as a maximum permissible exposure for individuals within the general population. Higher exposures are allowed by these Guides when determined to be in the national interest, the 500 mr dose being one tenth of that exposure allowed to workers in the nuclear field. It is expected that it will be possible to stay within the limits suggested by the FRC guides.

Basic safety objectives for all aerospace nuclear power devices have been developed. Namely, that:

(a) Under the most adverse conditions, these devices do not add materially to the general background atmospheric radioactivity;

(b) The use of these devices at a launch pad, operational base, or test range be such as to contain all harmful radiation, either within the device itself or within the prescribed exclusion area;

(c) On return to earth, the devices do not create a local hazard for people who might happen to be in the area.

Specific Problems—Approaches

1. *Manufacture, Transportation, and Ground Handling*

The manufacture, transportation, and ground handling of aerospace nuclear power sources do not present unusual health and safety problems, and can be adequately covered by established AEC and ICC regulations.

2. *Experimental Information*

There has been an intensive nuclear safety experimental program for the nuclear aircraft since 1955. Expenditures of $4 million have been made by the AEC's Aircraft Nuclear Propulsion Office in the following major areas: (a) long-term biological effects of radiation from nuclear power sources; (b) meteorological diffusion studies; (c) fission product release during normal operations; and (d) patterns of release of fission products from a variety of nuclear accidents—potential sources, types and locations. A comparable amount has been spent for studies on shielding in aircraft. Also, the Division of Biology and Medicine of the AEC has made a similar contribution in its biomedical research program, in areas applicable to aerospace nuclear power, and plans to take into account in its current studies any addition of C^{14} to the environment from direct neutron radiation from space power sources. This information has also served to give confidence to the safety analyses for nuclear ramjets, rockets, and SNAP devices.

Results of these studies indicate that hazards can be minimized by careful attention to engineering design, and adherence to the following operational safety features: (a) careful site selection with appropriate exclusion areas; (b) operation over water after launch; (c) precise knowledge of position; (d) selection of as long-lived an orbit as possible; (e) flights under favorable meteorological conditions; (f) development of countermeasure techniques; and (g) proof of reliability of the total system through an extensive preliminary testing program.

3. *The Manned Nuclear Aircraft*

In the design of a nuclear powered aircraft, considerable weight can be saved by the use of special materials in a divided shield, i.e., a portion of the shield is placed at the reactor, and the remainder at the crew compartment. Further, shadow shielding in front of the reactor will provide a core of reduced radiation to the crew. It is advantageous to have as great a reactor-to-crew separation as possible, but there is a point of diminishing return beyond which it costs less weight to add shielding than to extend the fuselage.

To evaluate crew radiation exposure, a Medical Advisory Group was established by the U. S. Air Force School of Aviation Medicine to suggest standards which would be acceptable to the AF along with the usual hazards of flight. They considered the sizable factor of safety built into the National Committee on Radiation Protection (NCRP) recommendations, and the

relatively high level of risk associated with any military flying, and proposed a tolerance dose for volunteer crew members somewhat higher than the quarterly occupational standards but roughly comparable in effect to the total allowable lifetime occupational exposure. This dose would be received within the training and operational period of ten years, and was deemed to produce a negligible biological effect in this age group.

The removal of the reactor will be the initial step of a major periodic maintenance check, and its reinstallation will be the final step before take-off. Thus, the bulk of the maintenance can be done readily. Inspection and repair of the reactor will be done in a special facility. This was demonstrated many times in Convair's successful flight program with the B-36 carrying a flight test reactor (July 1955—March 1957).

Operational bases for nuclear powered aircraft will require a radiation monitoring system and a large force of trained personnel performing detailed health physics work. "Permissible exposure limits" are expected to be within present occupational limits.

The aircraft normally would pose no public direct beam radiation threat, even if flying low. The principal concerns would be: (a) accidents which cause the release of fission products from the reactors, and (b) the dosage from exposure to leakage radioactivity (in the direct cycle concept).

If a nuclear powered aircraft were to crash, the heat in the reactor might melt the core if the coolant were shut off. A more serious but far less probable accident could occur if all the reactor safety controls failed in a certain sequence and the reactor "ran away." This event might vaporize the core, releasing a higher percentage of fission products than in a meltdown.

In a detailed study by Convair, the maximum doses which a person downwind from an accident would be expected to receive as the central concentration of released fission products blew past were found to be less than 25 rem beyond two miles for a runaway, and 0.8 miles for a meltdown.

Contamination of the ground vegetation from the falling out of the airborne fission products would also be possible, and makes it advisable to program flights over ocean areas or sparsely inhabited land corridors.

After considering the careful measures in programing take-offs and landings during favorable weather (lapse conditions), an analysis of the frequency and location of military and civilian air crashes would indicate a probability of less than one in 10 million that a populated area beyond the controlled area of the air base would be involved.

4. The Nuclear Ramjet (Pluto)

Since present plans call for the use of the nuclear ramjet only in time of war, the principal peacetime hazards occur with the flight testing. A coastal, offshore or island launching site leading to a sea test range would be required.

The ramjet missile would present two sources of radiation: the direct beam radiation; and the release of radioactive fission products. Since the reactor would be essentially unshielded, the direct beam dose to a person directly under a missile might exceed the maximum allowable "once in a lifetime emergency dose," and would be ample reason for conducting the low level tests over the ocean. At altitudes above 25,000 ft., the direct beam dose to a person on the ground would be negligible. The fission fragments released during flight would be from a line source, and thus would be well diffused initially. The fission release at any altitude above 500 ft. would be within allowable limits for the general population, by the time it had dispersed and drifted to the ground below.

5. General Launch and Range Safety Factors for Missiles and Rockets

Launch complex and range safety controlling factors are: (a) radioactive contamination of the environment; (b) conventional fire and explosion; and (c) the danger from falling objects.

Launch pad problems extending through the cone of destruct can be handled effectively by safety features inherent in missile range operations. If the vehicle lifts off in poor trajectory, the normal destruct devices operate with a high degree of reliability (failing less than one in 10,000). This reliability, coupled with accurate impact prediction and long-range communications, assures positive control.

6. SNAP Launch Complex Considerations

Special considerations for SNAP reactor units are:

(a) Radiation hazards from the fissionable fuel itself are negligible (less than 0.01 c for each reactor).

(b) Safety design requires that geometry shall prevent criticality as a consequence of: (1) immersion in water and rocket propellants, or (2) impact against a hard surface.

(c) Though designed to resist an accidental critical excursion, the potential hazard still exists. The worst conditions assumed for the SNAP 2 unit are: (1) a strong inversion weather condition, one hour of full operation followed by a 50 mw-sec. excursion, and release of all fission products. The radiation exposure directly downwind, at the center of the fission product drift, at 12 miles, is estimated to be less than 60 mr. It is apparent that this is a small hazard with very slight probability of occurrence. Orbital start-up circumvents even this.

For SNAP isotope units, the protection of the contained radioactivity from salt-water corrosion is important. The structural material of these units has been designed to remain intact in salt water throughout the effective life of the isotope used (100 to 500 yr.).

7. Nuclear Rocket Test Facility Considerations

For rockets, an analysis of the worst theoretically possible accident has been made, using Kiwi as the model (proof-of-principle rocket reactor, ground tested on July 1, 1959, July 8, 1960, and October 19, 1960). This assumes a full test run of the reactor, followed by a power excursion, core disruption, and release of the total fission product inventory under severe inversion conditions. The fission products directly downwind could produce a narrow area wherein the total dose from both external and internal radiation to individuals could be approximately 400 mr at a 5-mile radius, and 200 mr at 10 miles, during the first 13-week interval. Although the exposure dose at ten miles is greater than the recommended limit of 170 mr per yr. for members of the population at large, it is highly unlikely that an individual would remain stationary for the required exposure period. In fact, the dose received if one were to stand for an hour in the open at the center of the fission product drift, anywhere between 5 to 10 miles from the point of release (instead of remaining 13 weeks in the area) would be reduced to about 100 mr. Any move out of the center of the drift would, of course, result in much less exposure. The use of the vast Nevada Test Site for ground testing essentially eliminates this problem, and present information does not warrant restriction of project development.

It is anticipated that a Rover rocket could be flight tested in the Saturn system from Cape Canaveral: first, as an upper stage in a high altitude lob shot; and then, as an upper stage with orbital start-up, assuming adequate destruct control, on a southeast trajectory. These assumptions are based on existing missile trajectory and nose-cone re-entry data. Meanwhile, continued Rover static tests and experimental nuclear safety tests at the Nevada Test Site appear feasible.

8. Burn-up on Re-entry—Possible General Releases of Radioactivity

As an example of specific analyses of potential addition of radioactivity that

have been undertaken, the data for the SNAP 2 reactor are cited. Assuming complete burn-up and high-altitude dispersal of the fission product inventory at the normal termination of the mission, the fission product inventory injected into the atmosphere above 150,000 ft. would be about 2×10^5 c for each SNAP 2 unit after 1 yr of operation at 50 kw thermal. Selection of long-lived orbits would permit nearly complete decay of all noxious fission products before re-entry reducing the contained radioactivity to a few curies. Such orbits would permit centuries of cooling.

Special Engineering Design Considerations for SNAP and Rover

On an orbit injection trajectory, upon reaching a speed of 24,000 fps, a space vehicle would travel a maximum downrange distance of 10,200 miles. A speed of 25,600 fps is required to achieve a low orbit. Speeds of between 18,000 to 20,000 fps would carry a vehicle only 4,000 to 5,000 miles downrange. It can be seen, therefore, that the slope of the downrange distance curve rises very steeply with an increase in velocity just before achieving orbital speed.

1. SNAP Safety Design

Currently designed SNAP isotope and reactor devices have been thoroughly tested to be capable of burn-up on re-entry to the atmosphere at speeds above 24,000 fps for a burn-up time of 300 sec. or more (conditions met at 10,200 miles downrange). It is estimated that when this speed is reached in a pre-orbital failure, the vehicle will re-enter the atmosphere at an angle of less than 0.1 degree to the tangent, reaching temperatures above 4,000°F for over 300 sec., and a peak temperature in excess of 5,500°F for over 15 sec. Heat rates under these conditions are adequate to insure complete burn-up above 100,000 ft.

To facilitate exposing reactor fuel elements to aerodynamic heating, the structural materials surrounding the reactor are held together by fusible links that will melt at about 2,500°F, and allow the reactor components to fall apart on re-entry to the atmosphere.

It is concluded, then, that the isotope and small reactor devices being developed in the SNAP program can probably be flown safely with existing technology on either a polar orbit trajectory at the Pacific Missile Range, or a southeast trajectory (below the tip of Africa) at the Atlantic Missile Range. Both trajectories provide a 12,000 to 15,000 mile expanse of open ocean and Antarctic waste into which intact, or partially intact, devices which fail to achieve orbit can fall, insuring that speeds above 24,000 fps will be achieved before any populated land mass is encountered.

2. Nuclear Rocket Safety Design

For the Rover nuclear rocket, the major engineering design problem is to prevent random return of a hot nuclear reactor. As a booster, impact can be limited to the established missile range. A nuclear second stage rocket on an orbit trajectory, however, presents the problem of disposal of a hot reactor which theoretically could land anywhere along its trajectory if it failed to achieve orbit. An upper stage rocket might also soon return to earth due to a highly elliptical, low-perigee, short-lived orbit or to the application of thrust in the wrong direction due to control malfunction. In addition, both latter uses of the nuclear rocket carry with them the possibility of a cold reactor returning to earth.

Testing for Safety Reliability

1. Future General Test Objectives

Aside from the Pacific Missile Range polar trajectory, and the Atlantic Missile Range southeast trajectory, almost any other trajectory would overfly a populated land mass sooner. Before using such other trajectories safely, more precise information is needed on heat transfer during atmospheric re-entry, burn-up reliability, impact prediction of thrust devices, and patterns of distribution of radioactivity injected into the atmosphere on burn-up.

An extensive flight testing program to establish the empirical data needed to design for complete burnup and other safety features, and to prooftest the finished designs, has been established. Specific areas which will be explored in the experimental program are given in more detail below for each aerospace program.

2. Manned Nuclear Aircraft

To review the procedures for the protection of the public: the tests would be conducted during daylight hours; the test aircraft would generally use its conventional propulsion system for take-off, landing and flight to and from the test area; tests would be made during favorable weather conditions (lapse) to provide adequate diffusion; no person on the ground would receive a significant exposure, even if the aircraft were to pass 500 ft. or more directly overhead with the nuclear propulsion system operating at full power. The investigative program begun in 1955 continues with the objectives of further improving safety and increasing operational flexibility.

3. Nuclear Ramjet

Testing problems for the ramjet will be somewhat analogous to those of the aircraft and rocket. Due to its much more restricted testing period, however, the ramjet problem is expected to be considerably limited.

4. Nuclear Rocket Reliability for Safety

For the nuclear rocket, it will be necessary to develop techniques and equipment to achieve reliability of: controls, orbital start-up and shutdown, destruct controls and methods, and controlled re-entry techniques. A number of concepts have been considered, such as an excursion of the reactor core, disintegrative destruction with explosives, and the thermal shock and oxidation of flushing liquid oxygen or fluorine through a hot reactor. The use of deep space for disposal also merits consideration. It appears desirable to conduct a series of reliability tests to prove the safety for each intended use of the nuclear rocket systems.

5. SNAP Reliability for Safety

It might be possible to trade off a lower melting point core (which permits earlier burn-up on re-entry) for reliability of radioisotope containment at the launch pad. Although SNAP safety criteria are directed primarily toward personnel protection, the stipulation of containment of the isotope fuel under all launch pad failure situations is not an absolute personnel safety requirement, but rather serves to simplify procedures and eliminate the cost and delay of a launch pad contamination.

The present fuel core blocks are overdesigned to guarantee 100 percent assurance of radioisotope containment on the launch pad over all conceivable launch pad abort situations. Further, when they were designed, no consideration was given to now-conventional techniques for ejecting the device clear of an aborting vehicle. These techniques have now been developed and tested. An assurance of some less, but still acceptable, measure of launch pad safety might permit design of a fuel block for which burn-up on re-entry at speeds of between 18,000 to 20,000 fps would be assured. Burn-up could then be guaranteed at any speed which would carry the missile beyond 4,000 to 5,000 miles downrange. Answers to this problem will be sought in research work within a reasonable time.

For SNAP reactors, the problems similarly center around developing a reactor that can be vaporized and dispersed at re-entry speeds between 18,000 to 20,000 fps.

Special Subjects

No serious problem is foreseen in the contamination of extraterrestrial regions with radioactivity, or in the complication of long-range scientific studies on the origin of matter and on ambient space radiation.

Recent ambient space radiation studies have indicated that crew exposure on passing through the Van Allen belts, or during and after solar flare activity, may present a serious shielding problem—perhaps of greater magnitude than the requirement for crew shielding from nuclear power sources.

We can look ahead to the day when the use of aerospace nuclear power will be commonplace. By that time, an international accord in the registration and regulation of these nuclear power sources may be necessary.

Conclusions

Aerospace nuclear safety is an integral part of nuclear and flight technology. It is concerned with many complex human relationships. The advantages of nuclear power bring an attendant price. This price may be met by: man's absorbing unacceptable amounts of ionizing radiation; or accepting the handicap of weight required to shield and contain radiation sources. It is believed that the present National Committee on Radiation Protection and Measurement and Federal Radiation Council Guides provide a baseline for the protection of the population. Operational costs to achieve this protection, though admittedly high, can be kept within reason.

Appraisal of the radiation risks that have been discussed reveals them to be no more than those risks encountered in the progressive development of steam and electric power, the airplane, the automobile, or the rocket.

Just as the uses of these older forms of energy have been governed by considerations of safety, so too will the ultimate role of nuclear energy in space be in some measure determined by its safety.

Hydrofoils—Discussions and Reply

(Continued from page 29)

in fact, be more conservative than the empirical allowables established over the years in ship construction. This emphasizes the need for thorough loads research to enable efficient structural design.

It is also apparent that the relative importance of material properties must be established before a specific material may be designated as optimum for a particular hydrofoil application. Since no one material has all the good properties desired, there must be some compromise. We tend to feel that fatigue resistance is one of the more significant properties, particularly as affected by the salt water environment. While fatigue failure of a hydrofoil need not be catastrophic, development of effective operational systems must take full account of the relatively severe dynamic loading and corrosive environment. Experience developed in the aircraft industry can be utilized. This experience indicates that it is often not possible to take advantage of a material's high strength-to-weight ratio when fatigue becomes a design consideration. As a matter of interest, we are conducting a fatigue test for the Navy on the complete aft foil and strut assembly on the PC(H) program.

C. *Interference Effects*—Where hydrodynamic interference effects are involved, we would certainly agree that the blind use of past aerodynamic experience may lead to trouble, in aircraft as well as hydrofoils. The strut-foil-nacelle intersection configuration presented in Fig. 14 of the paper was improved because fillets placed on the top surface intersection reduced the critical pressures created by interference effects of the two surfaces. Examples from our design experience could be cited which indicate the superiority of either the high or midwing configurations for certain applications. This experience dictates that fillet studies in the wind tunnel are required for optimum solutions in aircraft. Similar studies in water tunnels are required for hydrofoils.

D. *Cavitation Delay*—With regard to delaying the onset of cavitation, transonic aerodynamics indicate that foil sweep or other planform effects may also be utilized. However, it is agreed that the increase in speed by this approach will not be large.

E. *Size Relationship*—It was stated that limiting the speed for hydrofoils to subcavitating designs requires acceptance of inherent size limitations which supercavitating operation will overcome. We are not in full agreement with this.

We agree that a supercavitating design may permit higher foil loadings, thus allowing reduced foil area for supporting the craft at high speed as compared with the same weight subcavitating craft. This, on the surface, would indicate that the geometric relationship between the foils and hulls as size increases would be easier to handle with supercavitating designs at high gross weights. However, the high foil loadings also result in proportional increases in take-off speeds unless auxiliary devices are used, as was stated earlier in the paper. The resultant high take-off speeds may be unacceptable due to increased power requirements, increased hull weights, crew and equipment habitability and other operational factors for a craft which must operate in a high sea state. The auxiliary devices required to reduce the take-off speed may well result in geometric problems on the same order of unwieldiness as the subcavitating designs.

Also, the present and near future state-of-the-art in propulsion machinery may represent a development area in increasing hydrofoil craft size. It might be noted that the preliminary drag and power comparisons of sub- and supercavitating designs presented in Fig. 15 would indicate an even higher ratio of power required for the supercavitating craft, had the condition selected for comparison placed the subcavitating craft in a cruising rather than incipient cavitation speed area.

From these considerations, supercavitating craft may require at least equal if not more development to obtain large increase in size than subcavitating designs.

Crossroads

For these and similar reasons, we feel that the crossroads might not be "toward limited small craft applications or toward larger, high-speed ships." We feel we stand at the same point as the aircraft industry once stood when it began to understand some of the problems of subsonic aircraft and began to consider supersonic flight. There are still many unanswered questions. Are the operational requirements of the hydro-

foil fully understood and are the development programs, both technical and operational, geared to optimize the system for each requirement? Are the developments in high and higher speed being accompanied by a proportionate effort to obtain greatly improved vehicle efficiency so that adequate payload and range will be available? Are the developments in military subsystems and weapons being pushed hard enough to insure that higher speed can be utilized? Are the subsystems, equipment and weapons being developed to meet the requirements of lightweight and marine ruggedness so that the craft may be optimized on size and speed? In other words, individual technical developments are not in themselves enough; a systems engineering approach must be taken to exploit the hydrofoil as an effective military system.

It is known that the Navy recognizes these questions and has started programs to obtain some of the answers. They cannot do this without help. We feel the aircraft industry can help and, recognizing that the paths are many, we at Boeing firmly believe in pushing ahead on more than one path and are actively joining in the search for the more promising roads.

Robert E. Bateman

Boeing Airplane Co., Aerospace Div., Seattle, Wash.

Importance

◆ The authors of this paper have rendered a fine service in reviewing the efforts of the U.S. Navy on hydrofoil craft, and outlining the present program.

I think we must all admit that development of craft of this nature has proceeded very slowly indeed since the war, in the light of their potential importance.

It is unnecessary to emphasize the importance more than to note the authors' own words. The modern high-speed submarine demands that there be surface craft capable of outpacing it in rough seas. The Navy has many problems, but this is certainly as important as any, and it has not received the emphasis which its importance warrants.

There are many reasons for this. One, as the authors note, is that aircraft manufacturers, the natural agents to develop craft that fly, even if their wings are in water instead of air, have until recently been busy elsewhere.

Another, which is mentioned but which deserves more consideration, is the difficulty of bringing to bear on the problem the joint efforts of naval architects and aeronautical engineers. The former sometimes fail to realize that hulls cannot measure up to the criteria which apply to surface craft, and still be properly designed for flight. The latter sometimes wish to carry over bodily the control concepts and instrumentation which apply to aircraft, whereas the control of hydrofoils in a seaway is a different problem indeed.

Third, there has been a lack of young engineeers, thoroughly grounded in the theory and practice of hydrofoils, nor has there been adequate provision for training them in the universities or elsewhere. When a few dozen hydrofoil craft are moving at high speed about our shores, this lack will soon be on the way to correction.

But, finally, there has not been the drive in the Navy itself which is essential to produce results. Those officers who have the vision and enthusiasm to tackle the problem, which involves as many difficulties as were involved in building the first really successful aircraft, have not been adequately encouraged and supported. This is not the place to discuss at length overall Navy policy, but the picture would be incomplete if it were not mentioned. With the advent of the A-bomb into warfare, dispersion of forces became as imperative on the sea as on the land. Suffice it to say that, while this principle has been recognized fully by many alert officers, the weight of opinion has not been such as to implant the concept widely. In particular, the problem of truly modern antisubmarine craft has not received the support its importance demands.

The authors' title gives me encouragement. If we are at a "crossroads," I trust we are now going somewhere with vigor and expedition.

There are many technical points on which I could comment and a few are worth discussing briefly.

The surface piercing hydrofoil craft has many uses, because of its simplicity and reliability. But, when it comes to handling tough seas, as the authors state, the submerged hydrofoil craft must be depended upon, because of the far lesser effect of seas upon it. It is also capable, as seems to be missing from the paper, of higher lift over drag ratios.

A reason for lag in development of submerged foil craft is the complexity of the controls. They have, in fact, been unduly complex, due largely to the use of aircraft controls under conditions where they apply only partially, rather than the development of controls explicitly designed for their purpose. It is amusing to read of the unpleasant contemplation of the fact that a submerged foil craft must fly under the continuous automatic supervision of its controls. Some such qualms delayed the wide introduction of commercial air transport. Well-designed controls are often more reliable in their responses than are men.

It is heartening to read of a broad program on supercavitating foils. There are some really tough problems here, and their solution is essential to craft of extreme speed. Fortunately, subcavitating foils take us into the useful range for the most immediate purposes.

The authors speak of a take-off speed which is half of cruising speed. I believe design can well aim at one third. In this connection, I trust that shrouded propellors, which improve thrust at low speed, are being fully considered. I also suggest that, in addition to the methods of power transmission considered, hydraulic transmission be also examined.

As is stated, one reason for the performance of hydrofoil craft at high speed is the avoidance of a limiting wave resistance. For small hydrofoil craft, wave resistance is indeed negligible. The criterion here is the load per unit length of foil, not the load per unit of area. With heavy craft, the effects of wave resistance again need to be considered, and the point at which they appear importantly seems to be about 1,000 tons. Above this weight, much can be accomplished by using optimum ratio of cruising speed to foil spacing, so that the wave effects of the two foils cancel to a substantial extent.

In considering dynamic stresses, the effects of orbital motions on foils is considered fully. But it is sometimes overlooked that they can also produce substantial stresses on struts. The stresses on struts during turns can also mount, unless properly taken care of. After all, struts act like foils, and can produce high lift when the apparent velocity is at a slight angle with strut centerline.

In conclusion, let me remark that, if we can have more papers as helpful as this one, we will indeed be making progress.

Dr. Vannebar Bush

M.I.T., Cambridge, Mass.

Competition

◆ It is a pleasure to comment on such a comprehensive and thorough job as this paper, "Hydrofoils at the Crossroads." The authors deserve the highest praise for covering such a broad and complex field with the technical acumen of the pure scientist.

For the record, the two 300-hp engines on the XCH-4 were 450 hp each.

Although the authors point out that the hydrofoil has its competition in the form of planing boats at the lower speeds, I feel that the possibility of retracting the foils to improve the low-speed range should not be overlooked even in large (300 to 1,000 ton) sizes.

The authors have divided the hydrofoil systems into two categories: submerged and surface-piercing, and discuss the advantages and disadvatages of each. It might be of interest to note that the 90-ton Maritime Administration craft is a hermaphrodite—the surface-piercing main foils have flaps on them and the tail foil is all movable. These control surfaces are operated on signals from a gyroscope and an accelerometer. They are designed to attenuate the response of forcing functions such as orbital motions in a following sea. This system will be tested later this year. Thus, we will not be dependent on the black box, but rather use it to overcome some of the disadvantages of the surface-piercing system.

One other point of note is the authors' conservatism in setting the barrier for subcavitating foils at 50 knots. We have a minor difference of opinion on this point as indicated by our 60-knot guarantee to the Maritime Administration. **William P. Carl**

Dynamics Developments, Inc.
Babylon, L. I., N.Y.

Feasibility

◆ I have read the authors' paper with interest, and it seems to me that they have aptly titled it "Hydrofoils at the Crossroads." Certainly, it is the first paper to my knowledge that enumerates the many serious design and operating difficulties that will have to be overcome before a hydrofoil craft can become a useful service vehicle. In the last 10 or 15 years, the hydrofoil boat has come a long way. I believe that feasibility has now been clearly demonstrated. The big remaining question yet to be answered is: Are hydrofoil craft desirable?

As the authors state, the advantages of the hydrofoil craft are reduced drag and a better ride compared to the same size planing craft. In essence this improvement is obtained by adding a hydrofoil system to a conventional boat. This immediately introduces problems because the weight of the hydrofoil gear has to come out of fuel, payload or basic structure. Inasmuch as neither the fuel load nor payload are ever large enough, the designer is forced to try to compensate for the weight of the hydrofoils in the basic structure. This forces the designer into aircraft-type weight control and aircraft-type structures. Furthermore, since aircraft engines are very light compared to marine engines, the designer is very strongly tempted to use aircraft engines despite their poor specific fuel consumption.

Having gone to aircraft-type structures and aircraft engines, the designer has saddled himself with a host of undersirable and possibly unfamiliar problems. The authors mention some of these problems such as corrosion, reliability, and fatigue. One problem not specifically mentioned is cost and there is some evidence that a 300-ton hydrofoil craft will cost about the same amount as a 3,000-ton destroyer. Another problem which is hinted at is maintenance. Aircraft engines and aircraft structures have costly and time-consuming maintenance requirements because of their low weights. The commercial airlines consider themselves well off when they keep an airplane airborne 8 hours out of the day. The Navy, because of severer operating conditions and because of the well-known difficulties with lightweight electronics gear, does not do as well. Assuming that the hydrofoil boat is easier to maintain than a Navy airplane, it seems probable that at least three, and more likely five, will have to be purchased to keep one on station. This means that there will have to be an enormous initial investment to perform any useful mission.

It is believed that the construction of the Maritime Administration test craft and the PC(H) are the correct approach. Operation of these vehicles will provide sound data on the desirability of hydrofoil boats. Desirability is tied to availability, performance, and initial cost. Performance and initial cost can be estimated with reasonable assurance but availability cannot as yet. This is now the key question and it will only be possible to answer it after extensive service trials.

It might be noted in passing that if availability is not considerably better than aircraft, then aircraft will be able to do many of the jobs of hydrofoil craft for less total cost. This is because the cost per vehicle seems to be roughly the same for hydrofoil craft and aircraft. Aircraft have roughly three times the speed of the hydrofoil craft. The availability of aircraft is very poor —what will it be for hydrofoil craft? There are a few sour old aeronautical types around who suspect the Naval Architect is on the brink of inventing the seaplane.

The authors are to be congratulated for bringing some of the problems of hydrofoil craft into the open for discussion. It is believed that if they are recognized as problems and intelligently attacked that there is some hope of reducing them to mere design difficulties. This is a sound and sensible paper which should be carefully read by everyone interested in hydrofoil boats or ships.

The opinions expressed in these comments are those of the writer and do not necessarily reflect those of the Bureau of Naval Weapons or the Navy Department at large.

F. W. S. Locke
Bureau of Naval Weapons,
Washington, D.C.

Stability

◆ The authors are to be congratulated for this timely and significant contribution to the hydrofoil literature. In reviewing this paper several points have particularly interested this reader, as here briefly noted.

Height Sensing

In the interest of historical accuracy, it should be pointed out that the 20-ft. research craft shown in Fig. 8 was first "flown" by means of an automatic stabilization system using height sensors of the electric contact or "rake" variety in July 1952. Progressive improvements in this means of height sensing were effected by my colleague and great hydrofoil enthusiast, Richard Browne, but it was obvious that an indirect means of height sensing was sorely needed. Accordingly, a program was initiated at the Flight Control Laboratory of M.I.T. to develop such a device, which eventually was placed aboard the 20-ft.

research craft in March 1955; the output being graphically recorded but *not* used as an input to the craft stabilization system since it was quite noisy. After extensive revisions and tests at Gibbs & Cox, Inc., this device was installed in the "Sea Legs" where, by dint of considerable personal effort, on the part of Mr. Browne during 1957 and 1958, the device eventually became a reasonably practical, relatively dependable height sensor.

Pitch Control

In discussing the control scheme employed in the "Sea Legs" the paper indicates that the smaller, forward foil controls the craft in pitch. Actually, pitch control is effected by means of the elevons on the large foil aft (which also are the means of roll control). However, it may be of interest to note that in the old 20-ft. research craft height *and* pitch signals were fed to the forward foil in a canard configuration.

Take-off Procedure

Under description of hydrofoil design features, the impression is given that desirable, normal take-off procedure would have the hull leave the water the instant minimum possible flying speed is reached. It is my opinion that a well-designed craft employing fully submerged foils should incorporate sufficient power to be easily capable of reaching a speed while in displacement, or nearly so, well above minimum possible flying speed before attempting take off.

Spatial Anticipation

Further along in this same section, the authors discuss "spatial anticipation." It may be of interest to note that one of the many configurations of the craft shown on Fig. 8 consisted of a canard foil system with single-rake type electrical height sensor at the bow. It happened that two wells had been provided in the craft for a foil assembly not used in this configuration. These wells were located aft of the craft center of gravity. A spare height-sensing strut was jammed into the well and connected into the system in place of the bow sensors. The craft flew satisfactorily, albeit a little sloppily! This might also be an appropriate moment to note that the 20-ft. research craft on several occasions was tested satisfactorily and at length while automatically stabilized and aerodynamically statically unstable in pitch.

Rate of Change of Lift Coefficient

Concerning rate of change of lift coefficient, this reader would agree that it is an important control parameter—but it is not considered that Fig. 17 contributes any information in this area. For some years, tank or tunnel test data concerning rate-of-change of lift of hydrofoils (as opposed to theory, in which the literature abounds) has been awaited. Once again, I suggest that it would be most enlightening to obtain some data at least for step changes in angle of attack of foils, both sub- and supercavitating.

With further reference to Figs. 17 and 18, would the authors care to comment on the shape of the curves applicable for superventilated foils?

Cost of Construction

Concerning structures, I would ask if the Navy is willing to pay the price of aircraft-type weight saving, and in this connection I would like to ask our brethren in the aircraft industry whether it is possible to estimate how much, on the average, the industry is willing to spend to save a pound on commercial or military aircraft.

Future Developments

In discussing future developments of hydrofoils and particularly stability and control, the authors correctly note that "... a great burden of reliability is placed on autopilot design." This is particularly so because, of course, there is no opportunity for a pilot to use up a few hundred feet of altitude while snatching control from the autopilot—in fact, it is yet to be shown that manual control of a large, relatively high-speed hydrofoil craft is feasible for any reasonably extensive period of time. Manual control has been tried on the "sea legs" and demands too much of the pilot.

Along this line of thought, however, one comes to the question of fail-safe design—a difficult thing to achieve. For instance, it is not yet clear that disengaging the autopilot is a suitable answer. Some would add means for automatically monitoring the performance of the system. Such schemes are costly, add complexity and may themselves cause failure. It has been suggested that the best approach in hydrofoil craft may not be fail-safe but "fail-soft."

In the area of stability and control, the possible benefits of studying the application of stability augmentation systems in surface-piercing hydrofoil systems, in particular, are worth mentioning.

Finally, I would like to take this opportunity to note that there is a current tendency to consider construction of very large hydrofoil craft, in fact larger than the largest aircraft, based on successful performance of relatively small craft. I suggest that considerable experience in the operation of an orderly size progression of useful hydrofoil craft is required to establish a firm practical foundation in "hydronautics." Further, considering the probable relative cost of hydrofoil craft as compared to conventional waterborne craft and aircraft, it behooves the marine industry to engage in more thorough studies and more extensive testing of prototypes, as is the practice in the aircraft industry.

L. E. Sutton
Gibbs & Cox, Inc.,
New York, N.Y.

Risks

◆ Referring to my discussion of the SNAME 1953 paper, reference 1, on Hydrofoils; my opinions have not changed and I am pleased to note, do not conflict with this paper. As I see it, for military purposes some calculated, or acceptable, risk may properly be justified. For other uses, the possibility of serious damage is not justified except under extremely unlikely rare conditions. No metal ship is unsinkable.

For hydrofoil craft hull weight saving is important. This should not be carried to such an extreme, certainly for nonmilitary purposes, as to result in a catastrophe if

1. Structural fatigue, or a submerged object, possibly a whale, damages the submerged units causing the hull to plunge to the surface.

2. During ocean operations, the hull must be waterborne during unexpected heavy weather that does not permit "flying."

Sydney A. Vincent
Consulting Naval Architect,
St. Petersburg, Fla.

Research

◆ Seven years ago Capt. Stilwell together with Mr. Buermann and Cmdr. Leehy presented a paper on our subject before the SNAME.

This publication was of an academic character but extremely useful because of its lucid exposition. Now, the authors have presented to us an eminently practical effort for which again we feel grateful since they describe the state of art reached by the U. S. Navy.

In the meanwhile, an impressive scientific development has taken place insofar as the theory of subcavitating profiles has been developed. Statements made on this subject by the authors are cautious. Nonetheless, we are obliged for this information since, on the Continent, our knowledge is extremely scarce. On the one hand, referring to the various types of craft described in the paper, this writer wishes to emphasize that the earlier—in his opinion unfortunate—ideas on a large low-speed transporter have been dropped. Although success has been reached in several cases, the rate of progress of development is very slow. On the other hand, it is fortunate that the U.S. Navy has tried to develop new systems of hydrofoils and has refrained from repeating successful European standards.

We are impressed by the theoretical work which is going on in the United States in our field but possibly progress could be reached more quickly if more emphasis would have been laid additionally on experimental ships and model research.

Prof. G. P. Weinblum
Institut für Schiffbau,
University of Hamburg, Germany

Reply

◆ We gratefully acknowledge the contributions of discussions to our paper and are thankful for the complimentary remarks of several contributors.

The historical record we presented stands corrected in several details and is interestingly elaborated in several areas. It is by no means painful to receive the added historical items; we would like to record that the discussors in several cases were principals. Even in the improved historical review as annotated by discussors, there are few name references to individuals contributing to the hydrofoil program.

The title of our paper is meant to look forward and several discussors have chosen to emphasize research or research together with progressive development craft as an important focus in the forward look. In this we agree; just as we were inclined to lengthen our brief history, we were tempted to expand our report on the current expansion in hydrofoil research. In this, however, we expect the technical record will speak for itself. As pointed out by Professor Weinblum, impressive scientific development has taken place; further, impressive facilities are being employed for hydrofoil research. Provided that design guidance is derived from this accelerated research, the physical basis for the future hydrofoil may be well documented. This is still not sufficient as was specifically reported by several discussors: the desirability or economic basis must also be sound.

We acknowledge that our paper has avoided the very important areas of military applications or military significance or military economy of hydrofoil craft. The cogent discussions are appropriate and are welcome. The total consideration of the hydrofoil potential for military or commercial applications will necessarily consider areas we avoided. The paper is, however, meant to report the "hydronautic" crossroads in the event such considerations as arising in the discussions eventually conclude the game is worth the candle.

Some particular technical areas discussed warrant further remarks. The acceptance of autopilots, for flight control or flight performance improvement, seems to range from tolerance to casualness. The tenor of discussion on structural and weight-saving matters supports the suggestion that the autopilot preferably should be "fail-soft."

The figures showing hydrofoil lift characteristics are meant to be schematic only. Several discussors have observed that progress in this particular area (or in the total field) has been slow. We have pointed out the Navy accelerated program; but, for the future, the technical record will have to speak for itself.

Similarly, the several speed figures are approximate. For example, in reply to Mr. Baker, the wake from the propeller in front of the hydrofoil in the configuration of Fig. 10 decreases the speed at which cavitation appears by about ten percent. Again, for example, we would expect that sacrificing some payload to permit larger foils (at constant displacement) should mean lower foil loading and an increase in subcavitating speed. These examples are intended to show that speed figures are illustrative and not rigorous.

Again we acknowledge the contributions of our discussors and also now the cooperation of our publisher.

J. J. Stilwell
P. W. Nelson
W. R. Porter

NOTE: Comdr. Nelson presented the paper at the IAS Twenty-Ninth Annual Meeting and this discussion was read at that meeting.

✦ ✦ ✦

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Data Capsule Ejection (Continued from page 9)

assumption that the flight characteristics were independent of R_N for $R_N > 10^6$. Data exist to assure the validity of this assumption for the blunt Mark 2 type design; but for the capsule, which is spherically shaped and, thus, subject to R_N effects in certain regions, it could not be ascertained whether R_N effects within the wake core were of significant concern. In the latter case, however, these effects would be minimized since both full-scale and model wakes were turbulent in nature. Actual simulation of the capsule's "jato" thrust unit also did not seem to be practical. This caused no concern since, in the absence of dynamic simulation, it was necessary only to thrust the model capsule from the nose cone with a known velocity, the method of ejection being quite irrelevant to the phenomena.

Thus, a model system was designed on the basis of:

1. Preservation of geometric similarity with full scale.
2. Preservation of relative inertial properties between the model nose cone and capsule.

Item 1 served to simulate adequately the basic flow about the nose cone, providing a similar flow region for the model capsule to traverse at various ejection velocities. Item 2 served to maintain a relative separation action between the two bodies which was ideally suited for the range and test equipment. In the absence of dynamic simulation, the test was therefore aimed primarily at an investigation of the wake/capsule interaction phenomena.

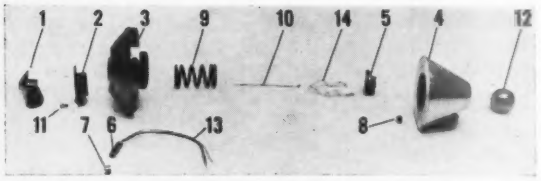

Fig. 1. Exploded view of capsule model showing: (1) spherical forebody nose section, (2) insulating forebody section, (3) cone frustum and antenna ring, (4) afterbody section, (5) capsule seat, (6) S-64 electric squib, (7) guillotine cutter, (8) spring compression adjusting screw, (9) spring, (10) spring retaining wire, (11) forward wire tie-down screw, (12) capsule, (13) squib lead, and (14) spring restraining cord.

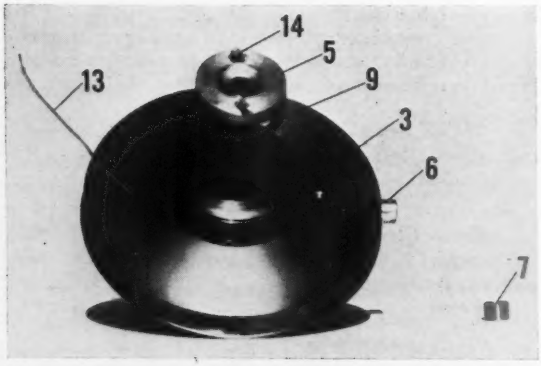

Fig. 2. (Refer to Fig. 1 for numerical identifications.) Model ejection system with afterbody removed.

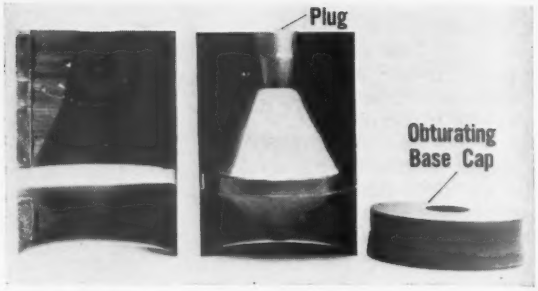

Fig. 3. Model and launching sabot, showing model assembly resting in one half of a split ethocel plastic sabot. Note plug that extends into afterbody to prevent the ball from rolling out during gun launch and model acceleration.

Model System

The model design (3.5-in. maximum diameter) is shown in Figs. 1 to 3. The nose cone was patterned after similar stability test models, and was modified to handle the capsule and ejection system contained in the afterbody.

A linear coil spring was used as the ejection mechanism. It was compressed within the afterbody, held there by a wire and then released by a simple cutting procedure to eject the capsule. The ejection velocity was controlled by the force of the spring. Wire cutting was accomplished by a guillotine action. The knife edge constituted one end of a cylindrical steel piece which was driven against the wire by expanding gases from an explosive squib. The squib was detonated when the model flew through two closely spaced sheets of foil which were connected to a large capacitor bank. The nose cone was electrically constructed in two pieces with plastic insulation between them. The squib constituted the electric path between the sections, and was fired when the respective model sections made contact with the double screen.

The models were launched from a smooth bore 90-mm gun; most of the models were launched at a Mach number of 0.8 (the full-scale design ejection point). Limited firings were also made at M = 1.6 and 2.5.

Data Processing and Analysis

Spatial location and time history measurements of the model nose cone were fitted by standard procedures[2] to yield a velocity and retardation history of the model. This gave a solution to the simple translation for the nose cone:

$$\ddot{Z}_1 = -\rho_\infty S_1 C_{D1} \dot{Z}_1^2 d_1 / m_1 \qquad (1)$$

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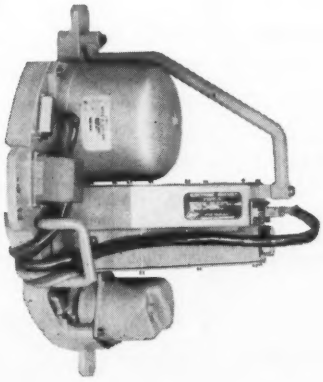

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An equation of similar form can be established for the capsule:

$$\ddot{Z}_2 = (-\rho_\infty S_2 C_{D2} \dot{Z}_2^2 d_1/m_2) \cdot f(L) \qquad (2)$$

where

$$f(L) = \rho_w C_{D2}' V_R^2 / \rho_\infty C_{D2} \dot{Z}_2^2 \qquad (3)$$

Eq. 3 now defines the wake effectiveness in terms of free stream conditions, and modifies Eq. 2 appropriately for each value of L. Note that V_R describes the drag producing velocity on the capsule in the wake, and $V_R \neq \dot{Z}_2$, except in free stream. Also observe that for $f(L) = 0$, vacuum wake conditions are described; for $f(L) = 1$, the free stream case exists. These two cases tend to bracket the regions of interest; but it should be noted that it is possible to have $f(L) < 0$ and $f(L) > 1$. In the former case, reverse flow wake regions would be present while in the latter case, density variations or R_N effects on C_D could result in higher than free stream drags.

The problem becomes one of determining $f(L)$ from the observed nose cone and capsule data, since all quantities in Eqs. 1 and 2 are essentially known except $f(L)$, the factor that will describe the wake/capsule interaction phenomena. Form the difference equation:

$$L = Z_1 - Z_2 \qquad (4)$$

and

$$L = \ddot{Z}_1 - \ddot{Z}_2 = \ddot{Z}_1 - (-\rho_\infty S_2 C_{D2} \dot{Z}_2 d_1/m_2) \cdot f(L) \qquad (5)$$

where $\ddot{Z}_1$ is a known function from the test and where the dimensions are taken as diameters (d_1) of the model nose cone. The measured relative distance between the capsule and nose cone, L, were set up on the plotting board of an analog computer and fitted by trial integrations of Eq. 5, using free stream values of C_{D_2}.[3] Initial relative velocities, $\dot{L}_0$, and the form of the function $f(L)$ were taken as trial parameters (an exact solution to the linear spring ejection system was made to guide the selection of $\dot{L}_0$).

Early attempts indicated that lack of sufficient data in close proximity to the model base negated any attempt to describe a small or weak reversal region. As a result, the convenient assumption that $f(L) = 0$ at the nose cone base was made for all ensuing trials. Trial and error established a convenient and adequate form for $f(L)$ as:

$$f(L) = a(1 - \cos \omega L), \; 0 \leq \omega L \leq \pi \qquad (6)$$

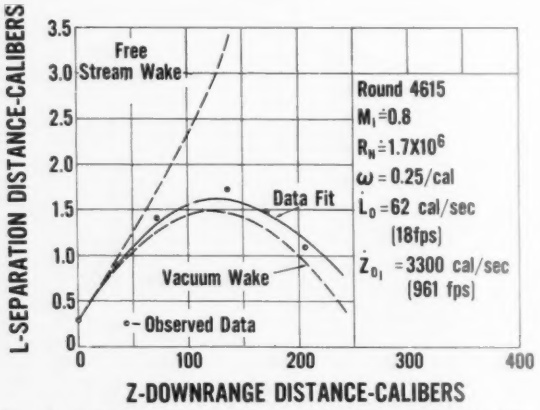


Fig. 4. Curve showing computer fits and data accumulated during tests.

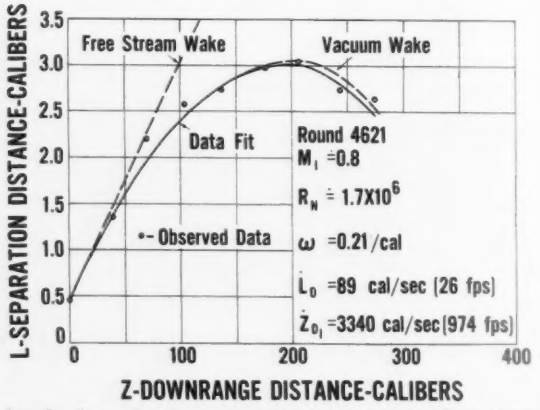


Fig. 5. Curve showing computer fits and data accumulated during tests.

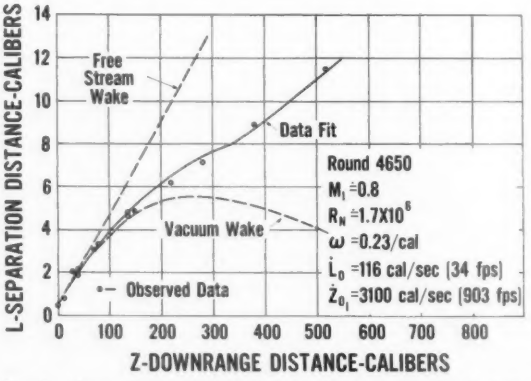


Fig. 6. Curve showing computer fits and data accumulated during tests.

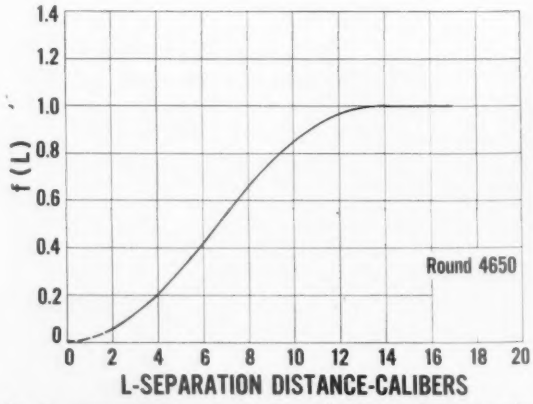


Fig. 7. Curve showing computer fits and data accumulated during tests.

Table 1. Summary of Results Obtained From Data Gathered During Tests

Round	Nominal Mach Number	No. of test Observations	Spring Force (lbs)	Maximum Separation Distance (calibers)	Initial Ejection Velocity (fps)	Remarks
4615	0.8	8	20	1.7	18	
4621	0.8	9	80	3.1	26	
4619	0.8	11	21	escape	14	yawed launch
4650	0.8	15	80	escape	34	
4618	0.8	6	60	escape	21	yawed launch
4622	1.5	5	80	1.5	20	
4649	2.5	4	80	0.6	7	

A value of $a = (1/2)$ permitted good fitting of the data; values of ω, of course, were dependent upon the actual phenomena which took place in each test firing. As a running check on computer operation, trajectories for each case were run with $f(L) = 0$ and $f(L) = 1$. This allowed a comparison of actual vs. synthetic cases, and assisted in the trial selections of ω. The data did not indicate the need for any use of $f(L) > 1$, hence the function was set equal to one for $\omega L > \pi$.

Selected curves of the data and computer fits are given in Figs. 4 to 7, and a summary of results is given in Table 1. On Figs. 4 to 6, it should be noted that $L \neq 0$ for $Z = 0$. This resulted from the test setup wherein separation had begun just prior to reaching the instrumented portion of the range. A typical series of pictures for the "non-escape" case is shown in Fig. 8.

Discussion of Results

Data acquisition was concentrated on the $M = 0.8$ case, and only here were $f(L)$ functions readily determined. When the capsule remained in the central wake core, escape was accomplished only for the largest ejection velocity. For this case then, the *model* system barely imparted sufficient ejection velocity, $\dot{L}_0$. Extrapolation of the data for the non-escape rounds [on the basis of the determined $f(L)$], and the data for the axial escape case indicated values of effective wake length (i.e., $f(L) = 1$) of about 15 nose-cone diameters. Based on the better fits, the *model* capsule would have had to travel to a point some seven calibers behind the nose cone to have its retardation rate exceed that of the model, and hence escape. To do this, a minimum initial relative velocity of about 35 ft/sec would be required.

On two rounds, nose cone yaw of some $\pm 30°$ occurred during the flight due to random mechanical perturbations that took place at launch. In both cases, capsule escape resulted even though the initial ejection velocities were considerably lower than two of the three cases previously cited. Effective wake lengths of some 4 nose cone diameters were found to exist in this case. This shorter length for the effective wake region is obviously attributable to the fact that the major wake contribution came from the outer portions rather than the central core of the wake flow. While such data cannot be said to yield complete basic information on the wake structure, they do suggest that, in the full-scale case, biasing the line of ejection away from the wake centerline can provide considerable "escape insurance."

The full-scale nose cone, at $M = 0.8$, would have less deceleration and would be less critical than the model case. In any event, given the function $f(L)$ from the model tests, the separation equations for the trajectory could be solved to determine the necessary capsule ejection velocity required in the full scale case.

In these tests, $f(L)$ was determined only for the high subsonic speed case and was, even then, made difficult by low ejection velocities. This is not, however, a general limitation on this test procedure. Recently, packagable devices that produced velocities equivalent to those obtained with 120 and 150 lb springs were statically tested, and the system did not appear to be limited at this point. Similar tests at Mach numbers up to 3 appear to be well within the present technique capability.

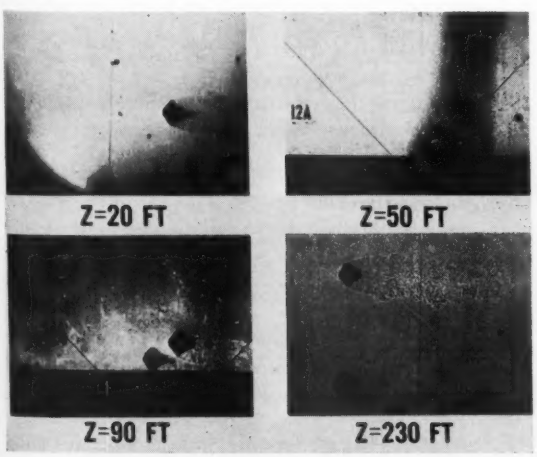


Fig. 8. Shadowgraph sequence of in-flight ejection. Note that capsule returns to nose cone (non-escape case) and must bounce off afterbody to reach free stream flow for separation.

References

[1] Rogers, Jr., Walter K., *The Transonic Free Flight Range*, BRL Report No. 1044, June 1958.

[2] Murphy, C. H., *Data Reductions for Free Flight Ranges*, BRL Report No. 900, Feb. 1954.

[3] Charters, A. C., and Thomas, R. N., *The Aerodynamic Performance of Small Spheres from Subsonic to High Supersonic Velocities*, JAS, Vol. 12, No. 4, Oct. 1945.

Aircraft Dynamic Response

(Continued from page 11)

parable results. These oversimplifications are employed to minimize the scope of the analysis yet derive the directional oscillation.

Analytical Approach

In accordance with the limitation specified in the previous paragraph, the period and time to damp for the lateral-directional mode can be established from only two equations—namely, turning ($\dot{r}$) and lateral ($\dot{v}$) acceleration around the Z axis and along the Y axis, respectively:

$$\dot{r} = [N_a - k_1 p q_1 - k_2(1 - S_1)\dot{v}]/I_z \qquad (1)$$

$$\dot{v} = (Y_a/M_t) + g \cos \text{Ⓗ} \sin \Phi - ur + wp \qquad (2)$$

Eqs. (1) and (2) represent the complete equations required to simulate the Sabre-jet within the prescribed tolerances[1] around the aircraft axes. A description of terms is given in Fig. 1 where the velocities, forces, and moments with respect to the various axes systems are as follows:

- u, v, w = linear velocities along airplane X, Y, and Z axes, respectively
- X_a, Y_a, Z_a = summation of forces along airplane X, Y, and Z axes, respectively
- X_s, Y_s, Z_s = summation of forces along airplane stability X_s, Y_s, and Z axes, respectively
- p, q_1, r = angular velocities about airplane X, Y, and Z axes, respectively
- L_a, M_a, N_a = summation of moments about airplane X, Y, and Z axes, respectively
- L_s, M_s, N_s = summation of moments about airplane stability X_s, Y_s, and Z_s axes, respectively

Since most coefficient data are given in terms of the stability axis, Eqs. (1) and (2) become

$$\dot{r} = \frac{N_s \cos \alpha + L_s \sin \alpha + Y_s d - k_1 p q_1 + k_2(1 - S_1)\dot{v}}{I_z} \qquad (3)$$

$$\dot{v} = (Y_s/M_t) + g \cos \text{Ⓗ} \sin \Phi - ur + wp \qquad (4)$$

where $Y_a = Y_s$ because of aircraft symmetry in the XZ plane. In Eq. (3) N_s and L_s are the turning and rolling moments about the Z and X stability axes, respectively. Symbol Y_s is the side force along the Y axis. The term $K_2(1 - S_1)\dot{v}$ is the yaw damping term and a function of a pilot control switch S_1. Symbols $k_1 p$ q_1 denote a cross-coupling term. The value of d is defined as the distance of the center of gravity from the 35 percent mean aerodynamic chord (MAC) point. I_z is the moment of inertia about the Z axis.

In Eq. (4) M_t is the instantaneous mass of the aircraft and ur and wp are the cross-coupling terms.

To establish criteria for the oscillation in the lateral-directional mode, the following assumptions will be made:

(1) Since the oscillation is to be only directional, the effects due to roll will not be included. Under these conditions, the rolling acceleration and rate ($\dot{p}, p$) are equal to zero.

(2) Since the duration of the oscillation is short, the change in air speed V_t and angle of attack α will be considered insignificant. Similarly, the pitch acceleration and rate ($\dot{q}_1$ and q_1) are equal to zero.

(3) The instantaneous mass is considered fixed, and the center of gravity location is at the 35 percent MAC point.

(4) Yaw damper is off—i.e., $S_1 = 1$.

(5) For simplification purposes:

$\cos \alpha = 1$ and $\sin \alpha = 0$ since $\alpha \cong 0$.
$u \cong V_t$ since $u \gg v$ or w.

Applying these conditions to Eqs. (3) and (4) yields the following results:

$$\dot{r} = N_s/I_z \qquad (5)$$

$$\dot{v} = (Y_s/M_t) - ur \qquad (6)$$

Since the oscillation is to be described in terms of yaw angle ψ and turning rate r, Eq. (6) can be modified by employing $\psi = -(v/u)$; therefore $\dot{v} = -u\dot{\psi}$ and Eq. (6) becomes

$$\dot{\psi} = -(Y_s/M_t u) + r \qquad (7)$$

In Eq. (5) N_s represents the total summation of the turning moments about the Z_s axis—that is,

$$N_s = N_\psi + N_{\delta_r} + N_{\delta_a} + N_{w_a} + N_p + N_r \qquad (8)$$

where each component of turning moment is defined as follows:

- $N_\psi = qSbC_{n_\psi} \times \psi$ (turning moment due to yaw angle)
- $N_{\delta_r} = qSbC_{n\delta_r} \times \delta_r$ (turning moment due to rudder surface deflection)
- $N_{\delta_a} = qSbC_{n\delta_a} \times \delta_a$ (turning moment due to aileron surface deflection)
- $N_{w_a} = qSbC_{n_{\alpha_a}} \psi f_1$ ($\measuredangle$) (turning moment due to inlet air momentum)
- $N_p = q(Sb^2/2V_t)C_{n_p}(p + r \sin \alpha)$ (turning moment due to rolling velocity)
- $N_r = q(Sb^2/2V_t)C_{n_r}(r - p \sin \alpha)$ (turning moment due to turning velocity)

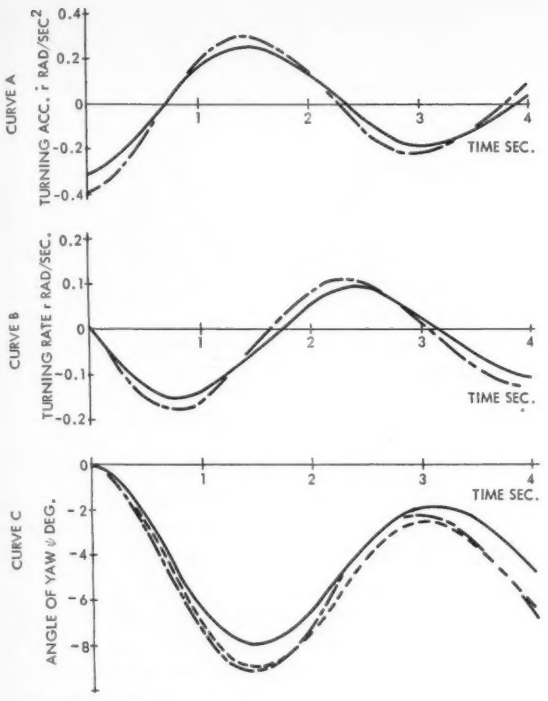
In Eq. (7) Y_s represents the summation of forces along the Y_s axis—that is,

$$Y_s = Y_\psi + Y_{\delta_r} + Y_{dt} + Y_p \qquad (9)$$

where each component of side force is defined as

- $Y_\psi = qSC_{y_\psi} \times \psi$ (side force due to yaw angle)
- $Y_r = qSC_{y_{\delta_r}} \times \delta_r$ (side force due to rudder deflection)
- $Y_{dt} = qSC_{y_{dt}} \times \psi$ (side force due to droptank as a function of yaw)
- $Y_p = (qSb/2V_t)C_{y_p}(p + r \sin \alpha)$ (side force due to rolling rate)

The equations for N_s and Y_s can also be simplified



TEST CONDITIONS:

1. MACH = 0.6; ALT. = 10,000 FT.; CLEAN, WT. 24,000#, C.G. @ 35.% M.A.C.
2. OSCILLATION LIMITED TO DIRECTIONAL MODE:
   SET $p = \dot{p} = \delta_a = 0$; FOR $t < 0$, $r = \dot{r} = v = \dot{v} = \delta_r = 0$;
   FOR $t \geq 0$, $\delta_r = 10°$.

Fig. 2. Lateral directional oscillation for a rudder step input. The solid lines are the estimated performance. The dot-and-dash lines show computer-calculated performance (UDOFTT). The broken lines show analog output from computer (UDOFTT).

by the criteria set forth previously and by stipulating the initial conditions for the test, which are as follows:

(1) The aircraft is initially flying in a steady straight and level flight with $\delta_a = \delta_r = \psi = 0$.

(2) The aircraft is in a clean configuration—i.e., landing gear up, drop tanks off, etc.

With these conditions, Eqs. (8) and (9) reduce to

$$N_s = N_\psi + N_r + N_{\delta_r} + N_{w_a} \qquad (10)$$

$$Y_s = Y_\psi + Y_{\delta_r} \qquad (11)$$

To further simplify Eqs. (8) and (9), the effects of N_{w_a} and Y_{δ_r} can be considered negligibly small in comparison to the other terms in the equations. Rewriting Eqs. (5) and (7) with the forcing function on the left side of the equation,

$$\frac{qSbC_{n_{\delta_r}}}{I_z} \times \delta_r = \dot{r} - \frac{qSb^2C_{n_r}}{2V_tI_z} \times r - \frac{qSbC_{n\psi}}{I_z} \times \psi \qquad (12)$$

$$0 = r - (qSC_{y\psi}/V_tM_t)\psi - \dot{\psi} \qquad (13)$$

let

$$A = -(qSb^2/2V_tI_z)C_{n_r}(M_a) \qquad (14)$$

$$B = -(qSb/I_z)C_{n\psi}(\alpha, M_a, h_p) \qquad (15)$$

$$C = +(qS/V_tM_t)C_{y_\psi}(M_a) \qquad (16)$$

$$D = +(qSb/I_z)C_{n\dot{\delta}r}(M_a, h_p) \qquad (17)$$

As seen in Eqs. (14) through (17), the coefficients are constants of the particular flight conditions and can be considered invariant for the period of the oscillation. Eqs. (12) and (13) become

$$D\delta_r = \dot{r} + Ar + B\psi \qquad (18)$$

$$0 = r - C\psi - \dot{\psi} \qquad (19)$$

The Laplace transform of Eqs. (18) and (19):

$$r(o) + D\delta_r(s) = (S + A)\, r(s) + B\psi(s) \qquad (20)$$

$$\psi(o) = r(s) - (S + C)\psi(s) \qquad (21)$$

Under the initial conditions specified previously:

$$r(o) = \psi(o) = 0$$

The period and time to damp can be established from the characteristic equations obtained when the determinant of the coefficient is equated to zero—i.e.,

$$\begin{vmatrix} (S + A) & B \\ 1 & -(S + C) \end{vmatrix} = 0 \qquad (22)$$

$$-[S^2 + (A + C)S + AC] - B = 0 \qquad (23)$$

Under the conditions specified for this test, $S_{1,2}$ is evaluated as

$$S_{1,2} = -0.1855 \pm j\,1.98$$

where one time constant is 1/0.1855 or 5.39 sec. The period of the oscillation is $\omega = 2\pi/T = 1.98$, $T = 3.17$ sec.

To analyze the influence that a step input to the rudder $\delta_r(s) = \delta_r/s$ would have on the system of equations requires only to solve the system of transform equations algebraically for the particular term in question and obtain the inverse in either case.

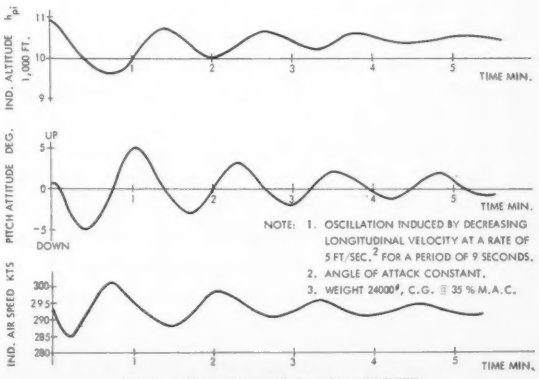


Fig. 3. Phugoid oscillation for UDOFTT.

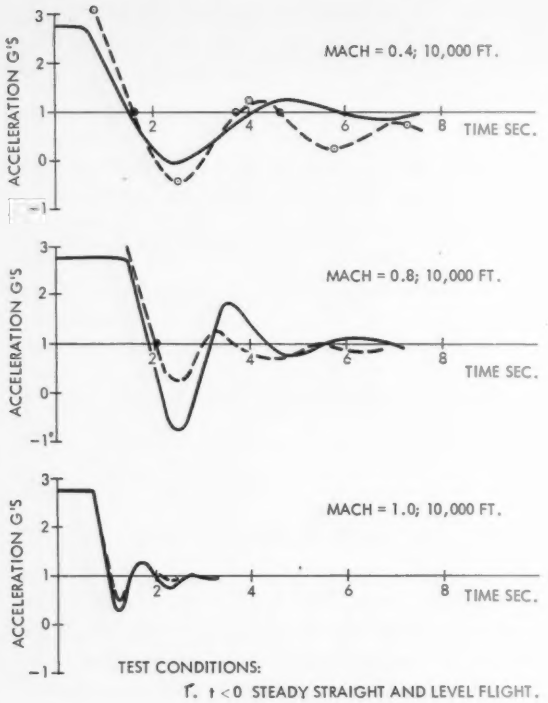


Fig. 4. Dynamic longitudinal stability (short period), 10,000 ft. Solid lines indicate estimated performance. Broken lines are UDOFTT.

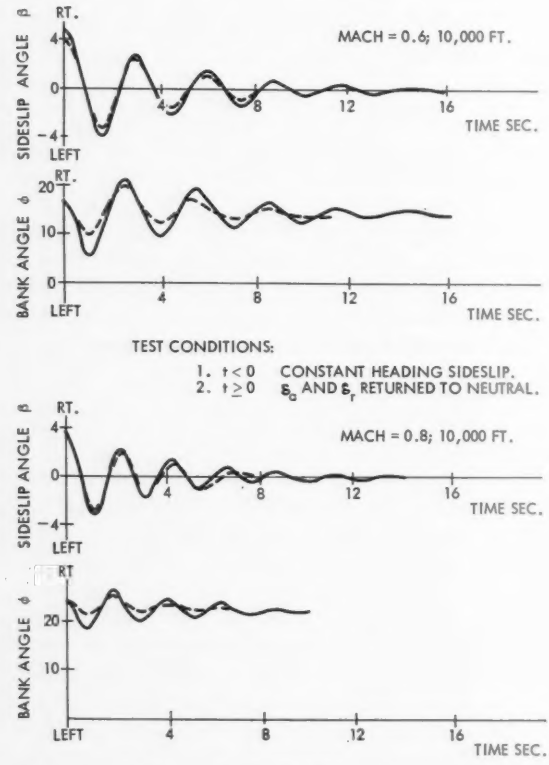


Fig. 5. Dynamic lateral directional stability, 10,000 ft. Solid lines indicate estimated performance. Broken lines are UDOFTT.

$$\psi(s) = \frac{\begin{vmatrix} (S+A) & D\delta_r/S \\ 1 & 0 \end{vmatrix}}{\begin{vmatrix} (S+A) & B \\ 1 & -(S+C) \end{vmatrix}} \tag{24}$$

$$r(s) = \frac{\begin{vmatrix} D\delta_r/S & B \\ 0 & -(S+C) \end{vmatrix}}{\begin{vmatrix} (S+A) & B \\ 1 & -(S+C) \end{vmatrix}} \tag{25}$$

The inverse for the preceding transforms takes on the form

$$k_1\delta_r\{1 - e^{-1.1855t}(k_2 \cos 1.98t - k_3 \sin 1.98t)\}$$

A plot of $\psi(t)$ and $r(t)$ which was a direct result of this computation is illustrated in Fig. 2 as a solid line. The computer calculated values are represented as dash-dot lines, while the dash line is the output in analog voltage form.

The results compare favorably with the estimated performance. It should be pointed out that the computation performed by the computer does not neglect the effects which were considered negligible for purposes of simplifying the analytic computation—i.e., coefficients A, B, C, and D invariant, influence of nonlinear computation due to large step inputs, disposing of particular terms because they yielded negligible effect in comparison to the significant terms, etc.

Fig. 2 also contains a demonstration of the results obtained by the method of integration employed by UDOFTT. The method adopted for use within the trainer was the integration formula suggested by the University of Pennsylvania[3]—that is, the Mod Gurk integration routine. For UDOFTT, the integration formula time interval h of 0.05 sec. was employed. The Mod Gurk integration formula used is as follows:

$$Y_n = A_0Y_{n-1} + A_1Y_{n-2} + A_2Y_{n-3} + h \times [b_0\dot{Y}_n + b_1\dot{Y}_{n-1} + b_2\dot{Y}_{n-2}]$$

where

$$A_0 = 1.1462084,\ A_1 = -0.2010870,\ A_2 = 0.0548787$$

$$b_0 = 1.6415864,\ b_1 = -1.0080130,\ b_2 = 0.275971$$

It is evident from the integration formula that the digital computer solves the differential equation by solving recurrently associated difference equations. Since this is the case, it has been shown[4] that three sources of error are possible between the true solution and that obtained through the use of the numerical integration formula:

(1) Round-off error due to finite word lengths.

(2) Truncated error, since both the number of terms in the integration formula for the interval of computation and the time interval between successive computations are finite.

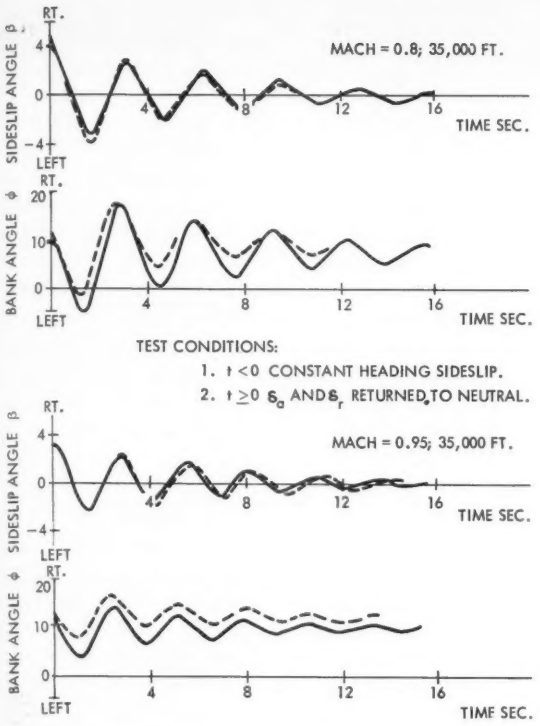


Fig. 6. Dynamic lateral directional stability, 35,000 ft. Solid lines indicate estimated performance. Broken lines are UDOFTT.

(3) Since the solution obtained with the formula is not a true solution, it is possible that parasitic solutions can result which could suppress the approximate solution.

As a demonstration of the ability of the Mod Gurk integration routine, Fig. 2 illustrates a comparison of the integration established using the numerical integration formula. In Fig. 2, curve B is the result of an integration of curve A.

Although the possibility of a discrepancy exists because of round-off and truncated error, the Mod Gurk integration formula does not exhibit parasitic solutions. This is evident in Fig. 3 where a phugoid is demonstrated. In this test, the integration is conducted over an extensive period of time (over 3,000 computation cycles) where the changes are small and infrequent.

The performance shown in Fig. 2 and explained in the succeeding text indicates that an interval of 0.05 sec. is adequate to describe the dynamic response of aircraft. Fig. 4 illustrates that an oscillation with a period of one second has been favorably reproduced.

In terms of amplitude duplication, the results show (Fig. 2) that the rudder is more effective in the trainer than estimated. This consequently gave a larger initial turning acceleration $\dot{r}$ and a final angle of yaw (ψ). Neglecting this fact, it is apparent that, considering only the amplitude of the response, the Mod Gurk integration yields satisfactory results for this period of 3.17 sec.

The results as shown in Figs. 4 through 7 are based on the airframe manufacturer's estimated performance—i.e., the solid line curve is the result established from coefficient data. The dash line is indicative of the degree of simulation together with the response of the computer—i.e., how well the coefficient data were duplicated and the ability of the computer to reproduce the response employing these simulated coefficients.

In this regard, the performance shown for constant heading sideslip agrees very well with estimated performance. In every case, the period and damping fall within 5 percent of the estimated values. The allowable tolerance for the period and time to damp is 15 percent of estimated performance.

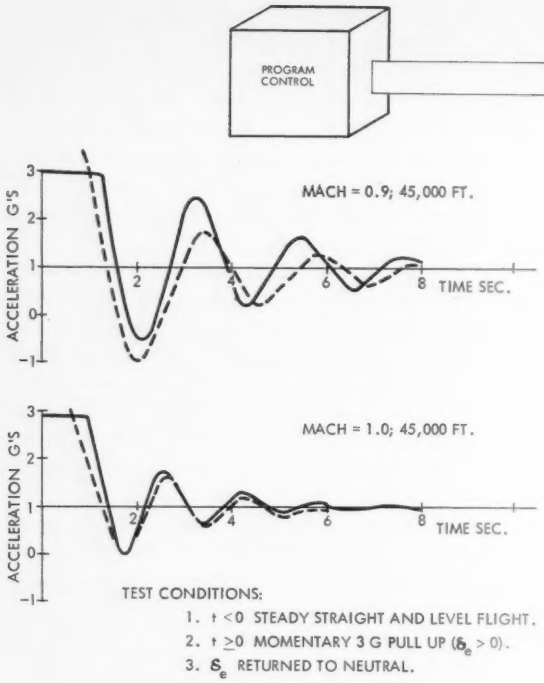
Fig. 3 illustrates the ability of UDOFTT to reproduce oscillation over a long interval of time. As a demonstration, a phugoid oscillation was established. The establishment of this phenomenon demonstrates that UDOFTT can discern small incremental changes within the computational program; it indicates, further, that the Mod Gurk integration formula is stable over long periods of integration.

Conclusions

Although the results shown in Fig. 2 illustrate the capability of the digital computer in real-time computation for only two degrees of freedom, the complete system of equations solved by UDOFTT is in orders of magnitude much more complex. The significance of UDOFTT is that it demonstrates that a digital computer has the capability of reproducing the dynamic response of various systems (such as the response of a high-performance aircraft) in real-time. In UDOFTT at present, the maximum response is limited to 10 cycles/sec. (A complete solution is obtained every 50 millisec.)

This solution rate appears to be quite adequate for present-day aircraft; however, it is by no means the limit in the response that can be attained. It can be concluded from the equations describing the motion and position of an aircraft that the frequency of solution for some equations does not require a solution rate of 50 millisec—e.g., instantaneous mass, Mach number, etc. Since this is the case, the response can be extended by increasing the solution rate on equations demanding a higher response. By altering the program in this manner, the response can be extended and will be limited only by the program time required and the basic speed of the primary building blocks. A further increase in the response can be realized through use of compressed time techniques, optimum programing, and higher speed building blocks.

A digital computer similar to UDOFTT can be employed in other systems requiring real-time solutions. In general, the digital computer can be used in most applications where analog computers



◀ **Fig. 7. Dynamic longitudinal stability (short period), 45,000 ft. Solid lines indicate estimated performance. Broken lines are UDOFTT.**

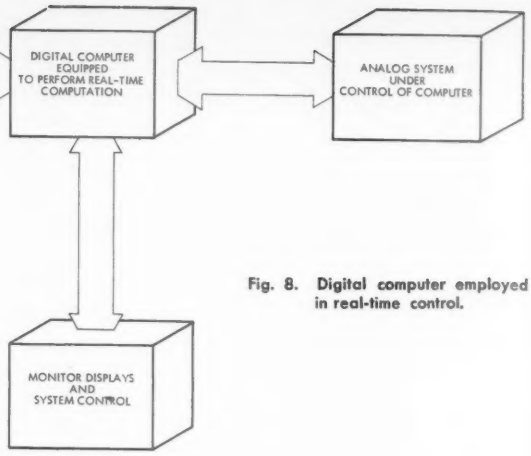

PROGRAM CONTROL
DIGITAL COMPUTER EQUIPPED TO PERFORM REAL-TIME COMPUTATION
ANALOG SYSTEM UNDER CONTROL OF COMPUTER
MONITOR DISPLAYS AND SYSTEM CONTROL

Fig. 8. Digital computer employed in real-time control.

are used. It exhibits superior small-motion dynamic properties as compared to its counterpart, the analog system. This superiority can be attributed to its ability to detect small significant changes in the steady-state condition and is a direct result of the high precision employed in the computations. The accuracy in the digital system is limited primarily by the precision employed and the limits of the integration routine.

Digital Computer Real-Time Applications

The application of the digital computer as a real-time control device is depicted in block form in Fig. 8. Since the computer is universal, any program can be introduced into it to establish real-time control. The computer is unique in that it is equipped with multiple analog input and output devices such that the computed program can drive or sense analog equipment. An example of this type of control would be general tunnel testing, the model would be driven dynamically by the digital computer to simulate a particular flight or stability condition. In turn, the computer would accept the analog test data and reduce these data to a suitable form for analysis. This type of dynamic testing would prove invaluable in yielding immediate results to all types of stability analysis of both missile and airframe design studies.

An explanation of some additional uses follows:

(1) The activating of tracking guidance equipment both to control the flight path and to obtain an analysis of the returned telemetered test data.

(2) The design and control of reactors—the digital computer can be implemented to control the process whereby the reactor becomes critical. It can be employed to make decisions in regard to responses obtained from various sensors within the reactor core. The program can be so written that the efficiencies and life can be predicted.

(3) As a research and development tool—since the computer is universal, real-time studies requiring constant correction and modification are easily handled by the digital computer by rewriting the portions of the complete computational program as desired.

(4) As a system checkout device—the digital computer can be employed to drive a complete servosystem, analyze its responses, and indicate any corrections. By the same token, the digital computer can be used to drive a particular servosystem to simulate some prescribed response.

It can be concluded that the digital computer, because of its universal nature and inherent capabilities, is not limited to flight simulation but can be utilized in numerous other applications.

References

[1] Connelly, Mark E., *Simulation of Aircraft*, M.I.T. Servomechanism Lab , Report 7591 R-1, Feb. 15, 1958.

[2] Goeckler, W. B., and Sherrill, R. D., *Dynamic Response of the Flight System Simulation for Aircraft Flight Simulators*, Aeronautical Accessories Lab., WADC, Report 57WCLE-1956, Aug. 1, 1957.

[3] *Simulation of a Supersonic Fighter Using a Digital Computer*, University of Pennsylvania, Report 55-20, May 1955.

[4] Kennedy, Owen W., Jr., Maroney, Richard, and Morse, Harrison, III, *An Experimental Analog–Digital Flight Simulator, Appendix III*, M.I.T. Servomechanism Lab., Report 45-2, Jan. 1959.

Gyro Damping (Continued from page 17)

pickoff are separated, as shown by the wavy lines in Fig. 1. This enables us to keep the electronics free from mechanical terms. To this end, we transfer the moment of inertia I_M to the gimbal axis by multiplying it by n^2, and we multiply the generated torque T_M by n. Each part of the block diagram will be investigated for optimal performance, after which they will be combined graphically for the stability investigation. (This method, which provides an easy analysis and a clear picture of the effect of the various quantities involved, is derived in the Appendix and in reference 1.)

(A) Platform at Rest

For the investigation of the platform at rest, we start with the block diagram of the gyrodynamics and copy it from Fig. 1, neglecting the disturbing forces on the left side, which are zero during this phase of the investigation (see block diagram A).

After eliminating the loop, we obtain block diagram B which is the transfer function F_g of the gyrodynamics:

$$F_g = \frac{\Psi}{T}(s) = \frac{H}{I_c I_\psi s^3 + (I_\psi D + I_c d)s^2 + (Dd + H^2)s} \quad (1)$$

Later, when we combine this function with the electronic function, we shall see that the negative inverse transfer function of F_g—namely, $-(1/F_g)$—is needed. In writing it down, we replace s with $j\omega$ and obtain

$$-\frac{1}{F_g} = jI_c\frac{I_\psi}{H}\omega^3 + \frac{I_\psi D + I_c d}{H}\omega^2 - j\frac{Dd + H^2}{H}\omega$$

$$\text{or} \quad = \frac{I_\psi D + I_c d}{H}\omega^2 + j\left(\frac{I_c I_\psi}{H}\omega^3 - \frac{Dd + H^2}{H}\omega\right) \quad (2)$$

By trial we find that in the range in which the various quantities change, the members Dd and $I_\psi D$ can be neglected, when $Dd \ll H^2$ and $I_\psi D \ll I_c d$, which is usually less than 2 percent.* Therefore, the transfer function is

$$-\frac{1}{F_g} \sim I_c\frac{d}{H}\omega^2 + j\left(-H\omega + I_c\frac{I_\psi}{H}\omega^3\right) \quad (3)$$

From this equation we see that the determining factors are as follows:

I_c	= moment of inertia of gyro and gimbal
H	= angular momentum of gyro wheel
H/d	= gyro gain
I_ψ/H or H/I_ψ	= gyro figure of merit

The torque motor coefficient D seems not to have a significant effect.

On Graph 1 several negative inverse transfer functions are plotted for the following values:

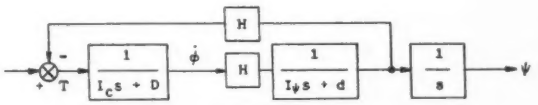
I_ψ	= 0.2	0.3			gr-cm-sec²
I_c	= 150	300			gr-cm-sec²
H	= 500	750			gr-cm-sec
d	= 40	25	37.5	60	gr-cm-sec

The first column represents values of an existing platform; the other values are variations in order to show their effect. Not all of them can be recommended. For the increase of H, it was assumed that the gyro frequency would be raised from 400 to 600 cps and the damping d also increased to keep H/d constant.

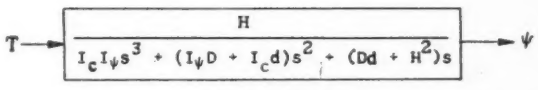
How the plot was worked out is shown in Graph 2A. The three vectors have to be calculated and added geometrically. All curves in Graphs 1 and 2A start at the origin, go along the negative imaginary axis, and bend to the left. After crossing the positive real axis, they remain in the first quadrant. The meaning of Graph 1 will be discussed after we have drawn block diagram C of the electronics, where the input is an angle and the output a torque according to our method of cutting the loop.

$$F_e = T/\psi = P \times K_1 \times G(s) \times K_2 \times K_M \times n$$

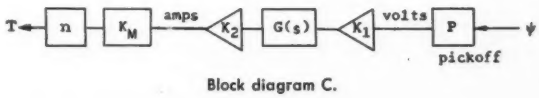
For the design of the electronics it would be necessary to develop this function accurately since



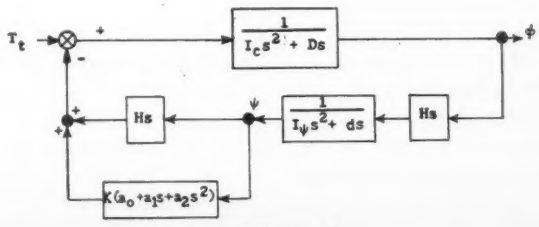
Block diagram A.



Block diagram B.

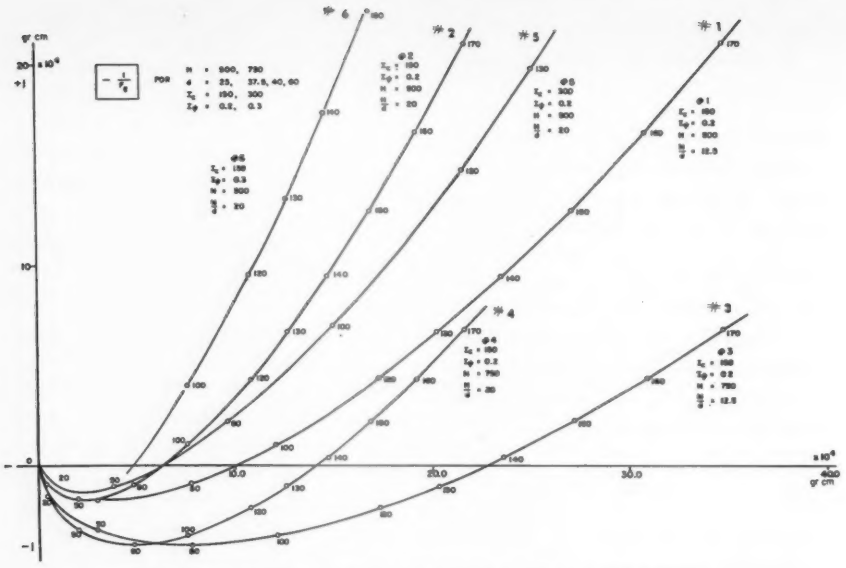


Block diagram C.

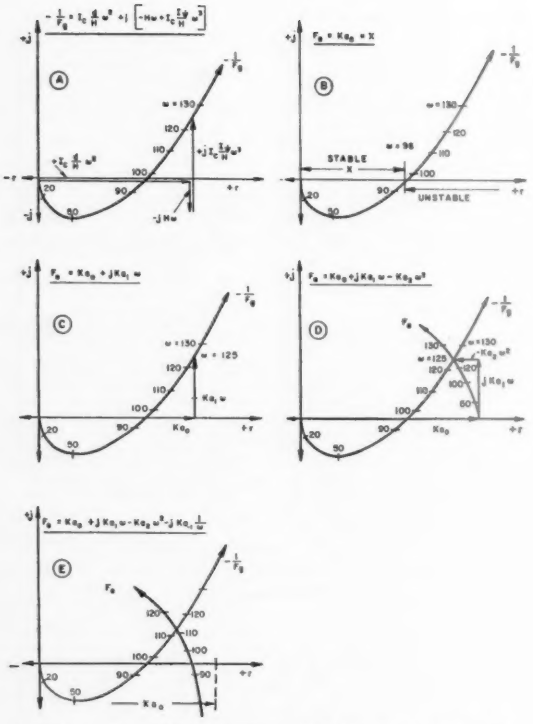


Block diagram D.

* This is not the case for a gyro whose precession axis is supported by air. Here $I_c d < I_\psi D$, and we may not neglect Dd and $I_\psi D$.



Graph 1. Negative inverse transfer functions of the single-axis platform.



Graph 2. The combined function $-(1/F_g)$ and F_e (do not scale).

it is more complex because of the filters used in the demodulator and modulator stages. However, for the investigation of the gyrodynamics—and this is the real purpose of this report—it is sufficient to use a simplified function:

$$F_e = T/\psi \sim K[a_0 + a_1 s + a_2 s^2 + a_{-1}(1/s)] \quad (4)$$

The correct function does not deviate too much from this in the frequency range where it will be used.

In the ω–domain, where we shall use it, it is written

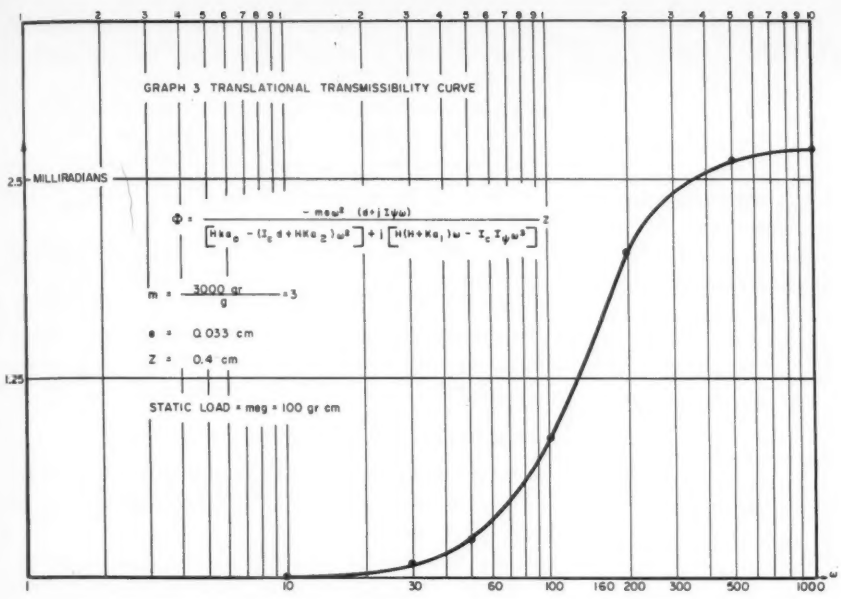
$$F_e = (T/\psi)(j\omega) = Ka_0 - Ka_2\omega^2 + j[Ka_1\omega - Ka_{-1}(1/\omega)] \quad (5)$$

where the first member Ka_0 is a static term and taken alone characterizes a proportional control system. The terms $Ka_1\omega$ and $Ka_2\omega^2$ increase the lead angle for higher damping, and the last term $Ka_{-1}(1/\omega)$ is the integral term that will eliminate any deviation when a disturbance persists.

We now come to the point where we can combine the functions $-(1/F_g)$ and F_e in order to predict the stability of the platform and study the effect of the various parameters (I_ψ, I_c, H, d, and K, a_0, a_1, a_2, a_{-1}). In order to keep the investigation as short and simple as possible, the stability boundary will be taken into consideration only, since this is sufficient for platform design. With additional work, of course, the operational frequency and the damping can be taken from the plot.* However,

* Several methods are possible; one should be mentioned here. Let us replace $j\omega$ by $-\delta + j\omega$ in Eqs. (3) and (5), where δ is the coefficient of damping in the servosystem. We get two new curves with the same value of $-\delta$. Where they cross each other is an operating point, if the two curves have the same frequency at the point of intersection. In order to meet the requirement of equal damping *and* frequency, it is advisable to plot families of curves for the two functions and search for the common point.

If we want to express the damping of the loop in percentage of critical damping ξ, we use[2] $\omega/\sqrt{\xi^{-2} - 1}$ instead of δ and write $-\delta + j\omega = -\omega/\sqrt{\xi^{-2} - 1} + j\omega$.



we are limiting ourselves to what must be done to get the systems just stable. The two functions will be combined graphically by drawing them in the same complex plane, as was done in the case of Graphs 2B–E.

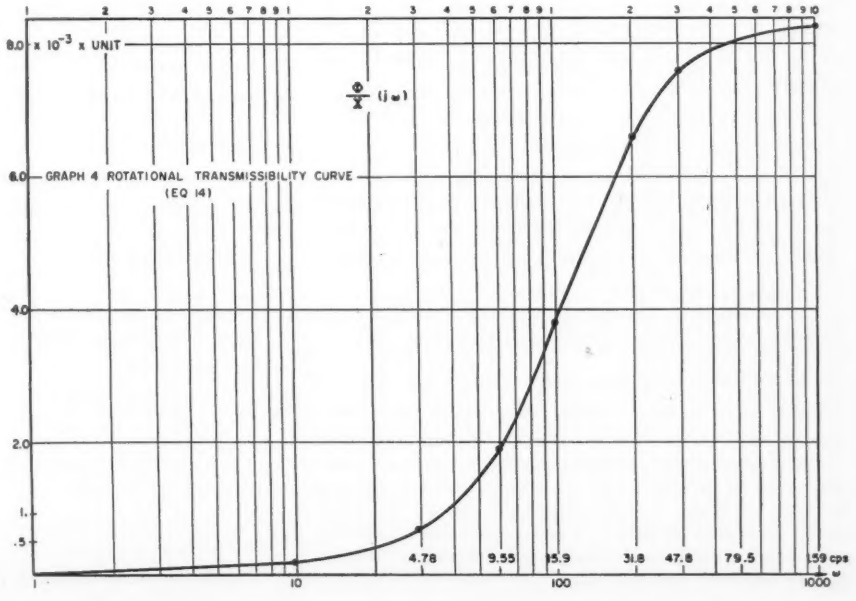
The method will be explained in the following four consecutive steps:

Graph 2B

A transfer function $-(1/F_g)$ is sketched which is similar to No. 1 of Graph 1. The curve crosses the positive real axis at a frequency of about $\omega = 96$. We select only the static member Ka_0 of the F_e-function and make it equal to x, the distance from the origin to the point where the curve crosses the real axis. The two functions must have the same scale and the same origin. Therefore, their unit vectors are concurrent, which represents our closing condition. We may now say that a disturbance T_i put into the system will pass through the system and will reappear at the other end as T_0 with the same magnitude and the same phase angle, which means that the system is undamped. If F_e is smaller than x, the system becomes stable; if F_e is greater than x, it will be unstable.

Graph 2C

If $Ka_0 = x$ does not provide sufficient static gain and must be increased beyond the intersection point, a second term $jKa_1\omega$ must be added in order



to bring the system out of the unstable region. This is shown in the graph. The frequency has increased to $\omega = 125$.

Graph 2D

It was required to raise the static term Ka_0 once more without an increase in frequency (because of limited torque-motor size). Therefore, a term $Ka_2\omega^2$ was added, which bends the F_e function to the left and avoids an increase in frequency.

Graph 2E

The integral term $jKa_{-1}(1/\omega)$ is added which cancels any remaining error and somewhat lowers the frequency of the system.

Returning to Graph 1, we know that:

(1) The negative inverse functions of the gyrodynamics are boundary lines for stability.

(2) The crossing point of the curves with the positive real axis should be extended as far as possible to the right to make static stability easy.

(3) The frequency spectrum should be selected so that the desired frequency is not far away from the real axis in order to avoid a large $Ka_1\omega$-term (2C) or a combination of $Ka_1\omega + Ka_2\omega^2$ (2D).

Curve No. 1 is calculated for values which were taken from an existing platform. The ratio H/d is 12.5. For a static term of $Ka_0 = 100{,}000$ gr-cm/rad, the system would be on the boundary of instability.

When we decrease the damping of the gyro and make $H/d = 20$, we come to curve 2 which is shifted to the left. Instability starts with

$$Ka_0 = (12.5/20) \times 10^5 = 62{,}500 \text{ gr-cm/rad}$$

Result: A small H/d is favorable.

Curves No. 3 and 4 have an H that is 50 percent higher than that of curves 1 and 2. The ratio H/d is kept the same for the corresponding curves; this means Nos. 3 and 1 and Nos. 4 and 2 have the same ratio. The new curves are shifted considerably to the right. Curve No. 3 would provide a damped system for $Ka_0 = 200{,}000$. The effect of an increased H is favorable and goes with the square of H, as we can see from Eq. (1). It also brings the desired natural frequency of the system ($\omega = 150$ or $f = 24$ cps) close to the real axis.* *Result:* It seems to be vitally important to make H as large as possible.

Curve No. 5 is calculated for a moment of inertia of the gimbal twice as large as for curve No. 2. $I_c = 300$ gr-cm-sec^2. The result is that the frequency scale is expanded far up, which is not at all favorable. The intersection points of the two curves are identical, but with increasing frequencies curve No. 5 shifts somewhat to the right. This advantage cannot compensate for the disadvantage caused by the increasing frequency. *Result:* Keep I_c as small as possible.

In curve No. 6 the moment of inertia of the gyro's precession axis I_ψ is 50 percent higher than for curve No. 2. The new curve is shifted to the left, and points of equal frequency are higher up. Both facts are not favorable. *Result:* Keep I_ψ as small as possible.

Final Results of This Section

Make H as large as possible for a given platform size and weight. Make d/H large and both I_ψ/H and I_c/H small.

The functions of Graph 2 can be evaluated quantitatively. For the designer, these rules are limited by mechanical and thermal stability considerations.

(B) Platform Subjected to Translational Oscillations

Translational oscillations affect the platform if there is a mass shift in the gyro cluster and its adjacent gimbals perpendicular to the direction of the oscillations. In Fig. 1, the mass shift is represented by the mass m at a distance e. Under accelerations in the direction of z, the platform is subjected to an oscillating torque $T_t = m\ddot{e}z$. Under its effect, the platform swings around the gimbal axis ϕ at the excitation frequency. The ratio of the platform's amplitude with respect to the excitation amplitude is given by the transfer function $\Phi/Z(j\omega)$, which we shall derive from the block diagrams of Fig. 1 rearranged for this purpose.

First, however, we simplify the function F_e in Eq. (4) by neglecting the term $a_{-1}(1/\omega)$, which is not required in this case.

$$F_e = K(a_0 + a_1 s + a_2 s^2) \tag{6}$$

See new block diagram D. From this we get

$$F_p = \Phi(s)/T_t(s) = \frac{\dfrac{1}{I_c s^2 + Ds}}{1 + \dfrac{1}{I_c s^2 + Ds} Hs \dfrac{1}{I_\psi s^2 + ds} [Hs + K(a_0 + a_1 s + a_2 s^2)]}$$

(where F_p = platform function) and simplify by virtue of the fact that the products Dd and $I_\psi D$ are negligible.

$$F_p = (\Phi/T_t)(s) = \frac{I_\psi s + d}{I_c I_\psi s^3 + (I_c d + HKa_2)s^2 + H(H + Ka_1)s + HKa_0} \tag{7}$$

The disturbing torque T_t is, as mentioned above,

---

* Since H/d is kept constant, d becomes larger, with increasing H. If we do not change d, the improvement in the stability is somewhat smaller, as we can see from a comparison of curve 4 with curve 1. The absolute value of d in curve 1 is $500/12.5 = 40$, while d of curve 4 is $750/20 = 37.5$. Curve 4 is not shifted as much to the right as curve 3 with $d = 750/12.5 = 60$, but the improvement of the frequency spectrum is not affected.

$$T_t = mes^2Z \tag{8}$$

which gives us

$$F_p = (\Phi/Z)(s) = \frac{mes^2(I_\psi s + d)}{I_cI_\psi s^3 + (I_cd + HKa_2)s^2 + H(H + Ka_1)s + HKa_0} \tag{9}$$

or, in the ω-domain,

$$F_p = (\Phi/Z)(j\omega) = \frac{-me\omega^2(d + jI_\psi\omega)}{[HKa_0-(I_cd+HKa_2)\omega^2] + j[H(H+Ka_1)\omega - I_cI_\psi\omega^3]} \tag{10}$$

Graph 3 shows the function $\Phi(j\omega)$ plotted for the following values:

m	=	3 gr-sec²/cm
e	=	0.033 cm
Z	=	0.4 cm
I_c	=	150 gr-cm-sec²
I_ψ	=	0.2 gr-cm-sec²
H	=	500 gr-cm-sec
H/d	=	20
Ka_0	=	200,000 gr-cm
Ka_1	=	3,000 gr-cm-sec
Ka_2	=	15 gr-cm-sec

For a given weight of the platform cluster (3,000 gr), the mass shift distance e was selected, in size and direction, so that the torque produced by the gravitation of the earth becomes meg = 100 gr-cm. In e should be included the amount of deformation caused by an additional acceleration in the direction of e. The curve shows a maximum slope when the exciting frequency reaches the resonant frequency of the system, around $\omega = 160$, after which it levels off. (The plot is calculated for a constant $Z = 0.4$ cm which gives a large increase in acceleration with higher frequencies. A more realistic curve should be calculated for $Z\omega$ = constant or $Z\omega^2$ = constant.) *Result:* In order to keep the platform's deviations small, we must keep d, the damping of the gyro, or e, the moment arm of the mass shift, or both, small. In Section A we favored a large d for easy stabilization. Therefore, we should try to make the structure of the platform rigid, but in this case also there are limitations. With a stiffer design, weight and moments of inertia go up, which is also not wanted. The designer must therefore choose some compromise. For example, he uses fixed ball bearings on both sides of the gimbal axes.

(C) Platform Subjected to Rotational Oscillations

The rotational oscillations of the aircraft to which the platform is attached play an important part in the design of the platform. If the platform has geared torque motors and the gimbal bearings and the slip rings have friction, forces are transmitted to the inner cluster which cause it to deviate from its desired position. In the block diagram of Fig. 1 we have introduced a disturbing torque that results from the geared torque motor. Its transfer function is

$$(T_r/X)(s) = n^2I_Ms^2 + n^2D_Ms \tag{11}$$

or, in the ω-domain,

$$(T_r/X)(j\omega) = -n^2I_M\omega^2 + jn^2D_M\omega \tag{12}$$

The calculation of the platform transfer function for this disturbing torque can be effected in the same way as was done for $T_t = mes^2Z$ above. We replace mes^2 by Eq. (11) or (12) and obtain

$$F_p = (\Phi/X)(s) = \frac{(n^2I_Ms^2 + n^2D_Ms)(I_\psi s + d)}{I_cI_\psi s^3 + (I_cd + HKa_2)s^2 + H(H + Ka_1)s + HKa_0} \tag{13}$$

or, in the ω-domain,

$$(\Phi/X)(j\omega) = \frac{-(n^2I_M\omega^2 - jn^2D_M\omega)(d + jI_\psi\omega)}{[HKa_0-(I_cd+HKa_2)\omega^2] + j[H(H+Ka_1)\omega-I_cI_\psi\omega^3]} \tag{14}$$

Graph 4 shows a plot of this function for the values $I_M = 0.0005$ gr-cm-sec², $D_M = 0.03$ gr-cm, and $n = 50$ and the values used in the example of section B. From this plot we determine the platform response to a rotational oscillation.

In the lower band from 0 to 5 cps the amplification factor is small, after which it increases rapidly in the vicinity of the resonant frequency of the system ($\omega = 160$) and levels off at approximately 1,000 cps. The factor d is responsible for the initial rise, while later on the $I_\psi\omega$ term becomes predominant. (Here, again, it should be mentioned that the curve is calculated for a constant angular amplitude χ which gives very high accelerations at higher frequencies. Therefore it is necessary to determine whether these conditions actually exist.)

From Eq. (13) or (14) and Graph 4, we learn that (1) the moments of inertia I_M and I_ψ, the viscous damping of the geared motor D_M, and the damping d of the gyro are responsible for the forced oscillations of the platform; and (2) the amplitude ratio Φ/X reaches its maximum slope at resonance.

It is therefore desirable to shift the resonant frequency of the platform to higher values. With regard to I_M, D_M, and d, two paths are open—make d small and keep geared torquers, or keep d high and use direct torquers.

With direct torquers, the term $n^2I_M\omega^2$ drops out and the term $n^2D_M\omega$ becomes $nD_M\omega$, where n is no longer squared. The term n^2 becomes unity, but the torquer has to provide n-times as much torque, therefore $nD_M\omega$.

Seen from the hardware side, neither of the two

paths really leads to an ideal solution. A geared motor has the advantage of lower weight, size, and power consumption than a direct torquer. However, it transmits energy into the platform system which causes oscillations. On the other side, the direct torquer is larger, heavier, and needs a large d.c. amplifier, but it has the advantage of transmitting only a small fraction of the energy which the geared motor transmits, and therefore the oscillation amplitude is kept to a minimum. In general one can say that the vibrations of the vehicle that carries the platforms, and the required accuracy of the platform, dictate the use of one or the other type of motor.

Gyro Rectification Effect

As mentioned in the introductory statement, the single-degree-of-freedom rate integrating gyro is subjected to a rectification effect if the platform oscillates around two axes. This effect, which causes the gyro to drift, will be explained with the help of Fig. 2.

Assume that under the effect of a torque around the ϕ-axis, the gyro has precessed through an angle ψ. Now, the vector of the angular momentum has a component along the input axis of the amount $H\psi$. If the platform turns simultaneously around the θ-axis, a torque $H\psi\dot{\theta}$ about the output axis ψ arises. Under this torque, the platform starts to drift around the input axis ϕ.

$$H\psi\dot{\theta} = H\dot{\phi}$$

or

$$\dot{\phi} = \psi\dot{\theta}$$

This drift effect can also be caused by oscillations of the gyro plate around the axes ϕ and θ. The two oscillations must be equal in frequency but must differ in phase so that one velocity component of one oscillation is in phase with the position component of the other oscillation, which will normally occur. Since both oscillations change their signs periodically, the drift occurs in one direction only. The mean value of this drift is $\bar{\dot{\phi}}$

$$\bar{\dot{\phi}} = (1/2)\Psi\omega\Theta \qquad (15)$$

expressed in angles of the gyro plate.

In order to bring in the aircraft motions, the plate angles ψ and θ are replaced by the airplane angles χ and ξ with the help of the transfer functions

$$(\Psi/X)(j\omega) = H(A/\Delta)$$

$$(\Theta/\Xi)(j\omega) = d(A/\Delta)$$

where A is the numerator and Δ the denominator of Eq. (14).*

If it is assumed that the two servoloops involved behave in the same manner—i.e., that they have identical constants A and Δ—Eq. (15) can be written in final form:

$$\left.\begin{aligned} \dot{\phi} &= (1/2)H(A/\Delta)X\omega d(A/\Delta)\Xi \\ \text{or} \quad \dot{\phi} &= (\omega/2)Hd(A/\Delta)^2X\Xi \end{aligned}\right\} \qquad (16)$$

Although the numerical values of $\bar{\dot{\phi}}$ are small (less than 0.001°/hour), the sense of Eq. (16) nevertheless supports our original statement concerning the importance of keeping the plate to which the gyros are mounted decoupled from the motions of the aircraft.

The Torque Motor

In conclusion, a word about the torque motor is in order. In our schematic of Fig. 1, the torque motor was divided into two parts, the rotor belonging to the "gyrodynamics" and the stator shifted to the "electronics." With regard to the gyro, we have discussed the effect of the moment of inertia, the damping of the rotor, and the gear ratio. With regard to the electronics, we have mentioned that the stator needs a controlled excitation in order to produce the torque. We have neglected any time delay in the production of this torque because normally it is less than one cycle for a 400-cps motor. With regard to the maximum torque of the motor, it can be taken from the equation

$$T_{max} = (Ka_0/n)\psi_{max}$$

where ψ_{max} is the amplitude of the precession angle.

The size of the torque motor, given by T_{max}, determines to a large extent the resonant frequency of the platform and the greatest disturbing torque the platform can withstand. Since the amplitudes of the aircraft's oscillations decrease with increasing frequencies, it is advisable to make the platform's resonant frequency high. This would provide high platform stiffness to offset mass shift effects and friction around the gimbal axes; but, at the same time, it would involve higher motor weight and more elaborate electronics. These are the penalties that would have to be paid.

Appendix

Servoloop Analysis With Negative Inverse Transfer Function

The following detailed information will prove helpful to those who do not have access to the literature[1] referred to in the text and who wish to familiarize themselves with the particular method involved.

The transfer function of the electronics is, Eq. (6),

$$F_e = (T_0/\Psi_i)(s) = K(a_0 + a_1s + a_2s^2) \qquad (A1)$$

where Ψ_i is the unit vector of the gyro precession axis angle (rad), and T_0 is the vector of the torque produced by Ψ_i (gr-cm). A plot of this function in the complex plane yields the curve shown in Fig. A1. With increasing frequency ω, the magnitude of T_0 and, in particular, its phase angle α increases.

* For the low frequencies in question ($\omega = 30$), the dynamic term $I_\varphi\omega$ was neglected as being small compared with d.

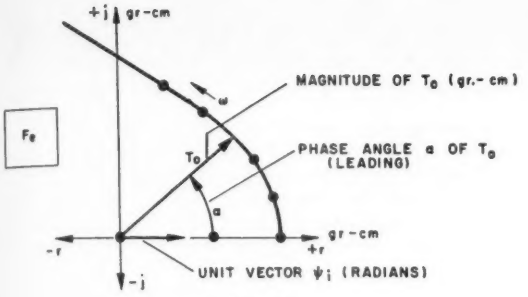


Fig. A1.

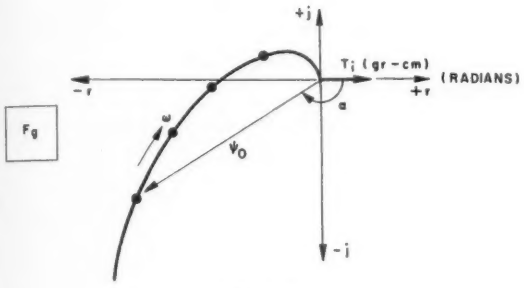


Fig. A2.

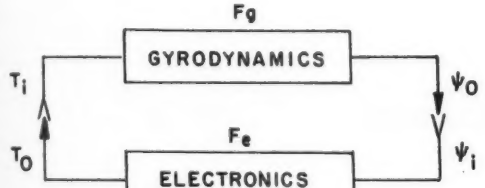


Fig. A3.

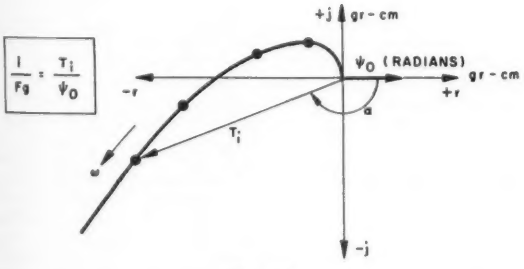


Fig. A4.

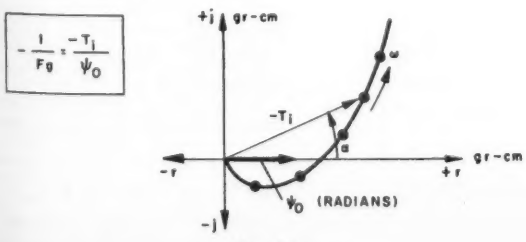


Fig. A5

We next take the transfer function of the gyrodynamics from Eq. (1) and neglect the small terms Dd and $I_\psi D$, as explained in the footnote on page 75.

$$F_g = \frac{\Psi_0}{T_i}(s) = \frac{H}{I_e I_\psi s^3 + I_e d s^2 + H^2 s} \qquad \text{(A2)}$$

In this equation, ψ_0 is the vector of the precession angle (rad) resulting from the unit torque vector input T_i (gr-cm). It is plotted in Fig. A2.

With increasing frequency, ψ_0 decreases and its angle of phase lag increases. As will be seen later on, we actually do not need this function. We have nevertheless plotted it in order to help in understanding the "negative inverse function" used in its place.

We now consider the complete block diagram, repeated for convenience in Fig. A3.

We shall use the transfer functions of the gyrodynamics and the electronics in the stability analysis of the complete system as follows. Let us insert a signal ψ_i and investigate its amplitude and phase as it issues as ψ_0. Since the two blocks are separated, we join them on the left by setting $T_i = T_0$, thereby providing a path for the signal.

If the output vector ψ_0 is equal in magnitude and 180 deg out of phase with the input vector ψ_i, the system oscillates continuously with constant amplitude. This means that it is undamped. When ψ_0 is greater than ψ_i, the damping is negative and the amplitude increases with time. When ψ_0 is less than ψ_i, the oscillations die out.

We shall now investigate the closing condition $T_i = T_0$, which we set up above. From Eq. (A1) we have $T_0 = F_e \psi_i$ and from Eq. (A2) $T_i = (1/F_g)\psi_0$. We see from this that we need $1/F_g$ and not F_g, which is its inverse, when we want to combine the two curves graphically.

Fig. A4 is a plot of $1/F_g$. This figure indicates the required vector T_i having the proper amplitude and phase α to produce a unit output vector ψ_0.

In the graphs of Figs. A1 and A4 the vectors T_i and T_0 are 180 deg out of phase, which prevents us from plotting one curve above the other. To obviate this difficulty, we multiply the inverse function $1/F_g$ by -1 to obtain the negative inverse plotted in Fig. A5.

This curve shows the required negative value of T_i having the proper amplitude and phase to produce the unit output vector ψ_0.

By doing this we have changed the closing conditions from $-\psi_0 = \psi_i$ and $T_i = T_0$ to $\psi_0 = \psi_i$ and $-T_i = T_0$.

With this in mind, we can plot the two functions F_e and $-1/F_g$ together, as shown in Fig. A6.

A signal ψ_i inserted into the electronics will appear as an output torque T_0 of the electronics. The torque T_0, now with opposite sign—namely, $-T_0$—fed into the gyrodynamics issues as ψ_0, equal in length and in phase to the input signal ψ_i.

In using this plot, one must bear in mind that at

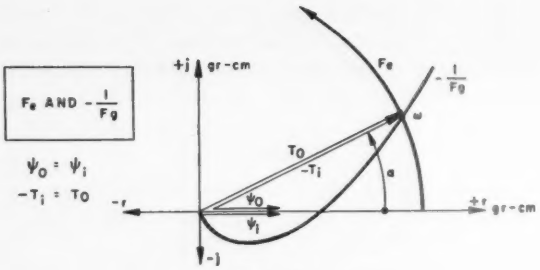


Fig. A6.

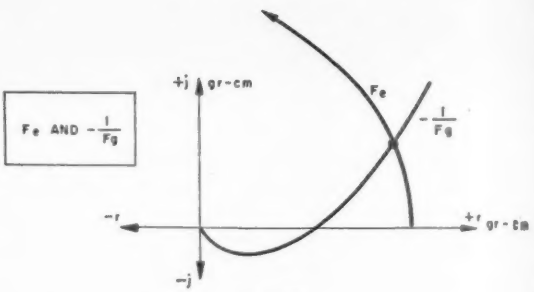


Fig. A7.

the point of intersection the two functions have the same frequency ω and zero damping.

To simplify the plot, the four vectors have been omitted from Fig. A6, and we obtain Fig. A7, which is the final diagram of our functions of the gyrodynamics and electronics.

Note: The functions F_e and F_g can be determined experimentally. This is not recommended, however, in the case of $-1/F_g$; the latter function should be calculated from the function F_g.

The scale used in Fig. A2 differs considerably from that used in all the others.

References

[1] Oppelt, W., *Kleines Handbuch technischer Regelvorgaenge*, University of Darmstadt, 1956.

[2] *Ibid.*, p. 275.

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